The Coming Revolution in Manufacturing

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New manufacturing technologies – exemplified by responsive design, moldless forming, and prototype simulation – will revolutionize the ways products are manufactured and marketed, permitting and indeed requiring the substitution of know-how for capital. Old notions of economies of scale will be stood on their heads as production runs shrink from thousands to single digits, while the voice of the customer will dictate design to a degree undreamed of today. We call this new way of making things „agile manufacturing." Its effects – on industry, the work force, and the education system – will be profound.

This article presents a realistic scenario of what agile manufacturing will look like. The scenario owes much to a recent Arthur D. Little Emerging Technologies Workshop, at which a select group of senior industry executives, government officials, and scholars came together to envision the future. Perhaps our most important finding was that the future is just around the corner. The radically different processes we envisioned are much closer to present reality than we had assumed. Despite its revolutionary impact, agile manufacturing requires no inventions. Industry leaders are demonstrating and implementing various aspects of it today. Full-blown agile manufacturing requires only the development and integration of currently available technologies.

To elucidate what we mean by agile manufacturing, we invite you to visit a hypothetical manufacturer, ABC Corporation, in the year 2010.

The Scenario

ABC manufactures small appliances and hand tools, which it markets worldwide. Its products are both customized and standardized – that is, they possess country-specific attributes (metric or English measurements, left or right drives) but are produced to global specifications, with parts that can be substituted among models. The company launches new products every few months. Many products designed for „niche" markets, such as ABC's new Japanese gourmet coffee maker, would not have been economically feasible back in 1993. All these achievements – simultaneous customization and standardization, frequent product introductions, and viable niche products – are due to ABC's product development process, which minimizes time to market.

The Product Development Process. At ABC, product development that took months and cost hundreds of thousands of dollars back in 1993 is now performed in days for thousands of dollars. All aspects of product and process design information are shared among designers, workstations, and software tools. Designers use CAD software and extensive databases to design both products and processes, then use CAE tools to evaluate them. Virtual prototypes are created in holographic form. Nothing is built until each aspect of the product and the process has been designed, optimized, and demonstrated in software. Once the product is accepted for production, the part geometry and specifications are downloaded to an expert system that controls the CAM equipment that produces tooling or parts directly.

This very fast product development process is far less costly than standard prototype evaluation and tool-making. Perhaps more important, the rapid product development allows maximum coverage of each product's life cycle window, which is often only three to six months. In addition, products can be designed to meet the latest customer requirements and can be quickly replaced or improved in response to market trends. The product changes are implemented in the production system through changes in the CAD product descriptions at little cost (by tooling) or no cost (by moldless forming). The CAM equipment, being flexible, facilitates product changes without the financial risk of process obsolescence.

A key feature of ABC's product development process is that it lets the company quickly and accurately determine product design criterion response to market needs, ensuring that the right product is available at the right time. Because agile manufacturing permits companies to respond faster and more precisely to the needs of customers, intimate and detailed market intelligence has become increasingly important as a way of achieving competitive advantage. Manufacturers get close to their customers by profiling market segments into extensive databases. For example, ABC cross-references credit card transactions to product bar code labels to extract trend data. The company also promotes focus groups and customer surveys to capture not only current market response to ABC's current products, but general needs and desires, which it values as the basis for developing new products. ABC spends nearly twice as much on these and other marketing activities (as a percentage of sales) as it did back in the 1990s.

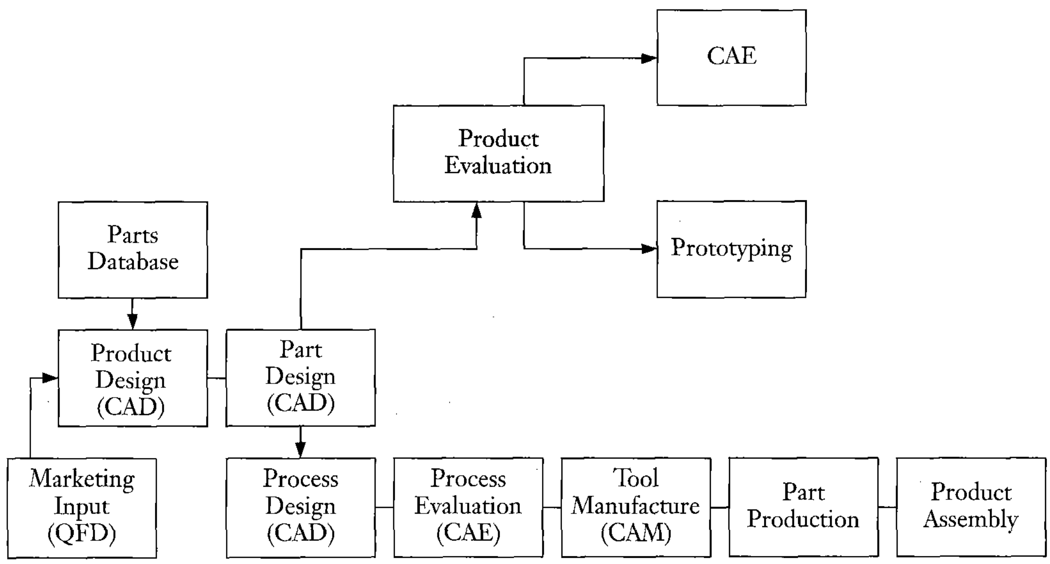
The Manufacturing System. ABC's manufacturing strategy follows from its goal: to achieve real-time response to market drivers. Its agile manufacturing system is so flexible that it can produce numerous parts on the same equipment with zero switching time. In other words, it has achieved *a lot size of one in a just-in-time environment*. This manufacturing system has a cost-volume relationship that is much flatter than those of the twentieth century.

The combination of flexibility and cost-effective/ lower volume production enables ABC to decentralize its production sites, locating them closer to its customers around the globe. Local production reduces distribution cost, while flexibility permits production on demand – obviating the need to store inventory. Each local production center has its own marketing group that continually surveys its customer base to get ideas for product improvement and for new products. Products are modified quickly in response to local market changes, and volumes are adjusted to local demand. Demand is triggered electronically from the retail outlets where ABC's products are sold, using electronic data interchange (EDI). Once this information reaches the factory, ABC's integrated computer coordinates production scheduling and orders material.

The schematic diagram in Exhibit 1 shows the generic components of an agile manufacturing system. Each function – e.g., CAD – may be represented by a number of technologies, such as geometric modeling, kinetics, and material specifications. Additional processes, such as holographic prototyping, can be inserted into the system as they become available. Key functions and their related technologies are shown in Exhibit 2.

Exhibit 1

Agile Manufacturing System Architecture



The Information Network. ABC maintains an information network that gives all the local production facilities access to up-to-the-minute changes in product and process design information. Open architecture and system software permit different application software packages operating on different hardware to communicate and share information. Design and design changes made at one node of the network are immediately available to the other nodes.

The network and the data are maintained and continuously updated by the central engineering staff at ABC's home office. These people provide technical guidance in product/process modification and coordinate ABC's „family" of standardized/customized products. It is their job to ensure that all facilities meet common standards for parts interchangeability and maintainability. They transmit new ideas developed at one facility to the other facilities and help out with their implementation where appropriate.

Links With Suppliers. ABC's rapid product development strategy, coupled with its local production on demand, have pushed the company to develop new, closer relationships with its suppliers of parts and materials. To respond quickly to the market and to eliminate inventory cost, ABC's suppliers must produce on time at facilities adjacent to ABC's local manufacturing facilities, rather than just deliver. ABC now provides floor space for its parts suppliers at each manufacturing and assembly plant, and it includes the suppliers on its own information network. Parts specifications, quantities, and production data are scheduled jointly by ABC and its suppliers. Like ABC, the parts suppliers maintain manufacturing equipment that lets them produce multiple components and component variants on the same machine with zero switching time and cost. The local ABC manufacturing facility and its suppliers become a virtual company – collocated and interdependent, sharing data, risk, and profit.

Exhibit 2

Agile Manufacturing: Key Functions and Related Technologies

Function	***Technology category***	***Component technologies***
Product design	computer-aided design (CAD)	*geometry, kinematics, material specifications, process and tool specifications*
Product evaluation	computer-aided engineering (CAE) rapid prototyping	*stress-deformation, dynamics, heat transfer, electromagnetics, other fields* *stereolithography, laser sintering, 3-D printing, holographic modeling...*
Process design	CAD	*machine tool paths, molding gates/risers*
Process evaluation	CAE	*deformation modeling (sheet forming, forging, extrusion, rolling), flow modeling (injection molding, casting), heat transfer (heat treating, casting)*
Tooling and die manufacture	computer-aided manufacturing (CAM)	*CNC machining, EDM, rapid prototyping and metal spray, 3-D printing*
Part production	CAM	*sheet forming, injection molding...*
Assembly	CAE	*design for manufacture and assembly, design rules/standards*

Environmental Protection. Environmental regulations have become a lot tougher since 1993. In many of its markets, ABC is required to take back its appliances when customers are ready to dispose of them. But ABC is not allowed to dispose of the returned products in landfills. Consequently, ABC has limited the materials it uses in its products to three polymers and several metal alloys, all of which can be recycled.

When used products are returned, ABC disassembles them and sorts the parts by material for recycling. This process has added another criterion to the product development process: design for disassembly and recycling. Serendipitously, limiting the number of materials used has provided significant secondary benefits, reducing the number of suppliers the company works with, reducing the material inventory required, and streamlining product development.

The New Work Force. The work force at ABC has changed considerably since the 1990s. The much flatter organization is made up of production, marketing, and administration. There is little unskilled labor. Product designers can now run the machines that produce their designs – a capability that lets them make design decisions that simplify manufacturing, reduce costs, and increase quality. Because workers are trained to operate a wide range of computer-controlled machines, ABC can choose flexibly among various processes for making products rather than always selecting the ones that are most familiar. Workers' grade and pay depend on the number of functions they can provide in both areas. Significantly, product development and process development are no longer considered separate skills. And ABC provides continuous education and training to keep its work force up-to-date on the technologies of both product development and production.

Military Capabilities. A key advantage of ABC's agile manufacturing is the company's ability to produce goods for the military – such as hand tools and cooking equipment – on demand. These goods are analogous to ABC's consumer products. They use standard commercial components whenever possible, but are designed to meet the special needs of military operating environments. Because ABC has the relevant CAD/CAM information files and contracts, and its production capability has been verified by test runs (with government paying for the capability validation), the military can begin production at ABC's facilities by electronic command.

Education System. Because workers now need highly specialized skills, companies no longer can afford to spend a long time training them – they must come into the company and contribute right away. Consequently, students and workers alike spend more time at school learning both applied sciences and specific technologies. Universities accept this broader mandate to prepare functional workers.

The Future Is Almost Here

The agile manufacturing described above is close to realization. Several leading companies have already implemented various aspects of our ABC scenario.

Digital Equipment Corporation has an integrated product/process development capability that lets the firm design a part, select the process for manufacturing it, and produce the tooling – a process that typically takes three to six months by traditional methods – in just one week. Thanks to integrated, centrally supported databases on materials and manufacturing processes, it is not unusual for a single engineer to design both the parts and the process, produce the prototype, and subsequently make the tooling. The same engineer uses CAE tools to evaluate part performance, e.g., heat transfer and stress-deformation, as well as process effectiveness, e.g., resin flow and cooling during injection molding. For design verification, prototyping machines use stereolithography to make geometric replicas of parts. Once the part design and process have been defined, tooling takes place on EDMs (electron discharge machines) or CNC (computer numerically controlled) machines that are on the local area network.

Sandia National Laboratory has bundled its casting technology into a package called Fastcast. Casting molds are designed on a CAD system with the aid of artificial intelligence. Designs are evaluated by means of CAE software that simulates flow, heat transfer, and solidification. Sandia then uses one of several rapid prototyping technologies to create a plastic model of the part, from which a mold is made. These molds are then used to create the ceramic molds by traditional means. Sandia will soon serve as a test site for the Soligen 3-D printing system, which supports the direct production of the ceramic mold from the CAD database, reducing the number of operations and the time required. Similarly, Allied Signal's aerospace division uses rapid prototyping to produce geometric replicas of turbine blades for aerodynamic property measurement and subsequently for casting mold production.

As mentioned on page 61 of this issue of *Prism,* in Ashok Boghani's article on „The Role of Government in fostering Innovation," the South Carolina Research Authority (SCRA) team has created a flexible computer-integrated manufacturing system called Rapid Acquisition of Manufactured Parts (RAMP). RAMP enables naval repair facilities to manufacture small quantities of needed parts on demand. The system networks CAD and CNC machinery to produce components in lot sizes of one. Aimed at developing the „factory of the future" for the Navy, the RAMP system is reducing the time spent waiting for spare parts by as much as 90 percent – from 300 days and more to just 30 days. Four RAMP systems are installed and operating, making printed wiring assemblies, machine parts, and gas turbine blades. Significantly, the RAMP systems are the first to employ the STEP and PDES standards that permit the international exchange of product specifications among different computer systems.

Meanwhile, technology development is proceeding apace. For example, Cambridge Consultants Limited (CCL), an Arthur D. Little affiliate based in Cambridge, U.K., has developed a new approach to shorten dramatically the time it takes to get new electronic products into the marketplace – and greatly increase the likelihood that they will be well received there. Presently, many consumer products fail because designers are unlikely to test designs on users until too late into the cycle for changes. The software simulation tools CCL has developed enable the designer to create an image of the proposed product's front panel on screen within two weeks of initial design. The product might be a video recorder, hi-fi, or medical instrument – any product for which ease of use is important. Each display element is represented by an individual graphic that can be controlled as if the product were already at the physical prototype stage. Sound or action responses are incorporated into the simulation. User problems are identified early and solutions can be tried and refined on screen. Integrating simultaneous engineering and computer simulation in this manner will shorten production lead times, increase designer productivity, and improve customer service.

Conclusion

The companies that are now pioneering agile manufacturing technology are seeing enormous reductions in time to market and product development costs. These benefits let them introduce more new products, update and improve current products more often, and produce smaller lots profitably – including specialized products for niche markets. In addition, agile manufacturing contributes to higher revenues by helping companies be first to market with the most customer-responsive products, capturing higher market share and receiving initial price premiums.

On the other hand, agile manufacturing will also permit many more competitors to enter the market, as barriers to entry will be far lower. To differentiate their products, companies will need to rely on know-how and responsive manufacturing. Companies that are not already actively exploring the benefits of agile manufacturing will find it increasingly difficult to compete.

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