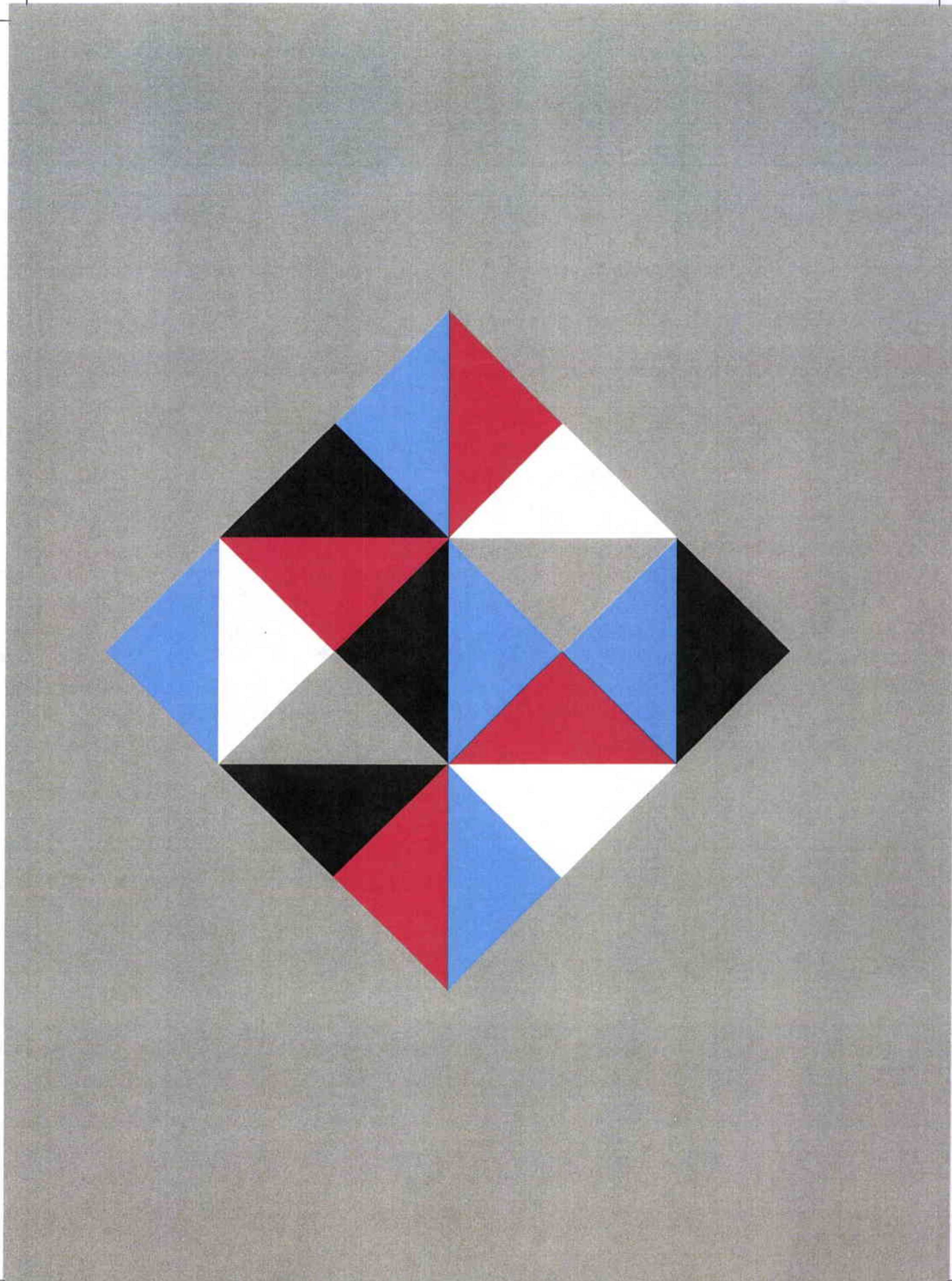


CHAPTER 9

The Future Of Manufacturing

Irene Petrick
Technology Trends

This chapter is a story about the future of manufacturing based on three predictions:

- that firms of all sizes will have increasing access to high-performance computing capabilities that will enable sophisticated modeling and simulation of both new products and production processes;
- that additive manufacturing will become commercially competitive across a wide range of industries and will support the use of multiple materials; and
- that new business models relying on information technology (IT) will reduce the administrative overload both of bidding and winning contracts and of delivering products and services.

If these predictions play out, it will favor localization of manufacturing over today's more centralized, economies-of-scale production models based most recently on offshore outsourcing. A fourth trend — a rise in the number of hobbyists who become designers and producers of one-off and small-lot products — will change the definition of "manufacturer" and may, in fact, return manufacturing to the garage. An IT-driven transformation in the manufacturing sector is inevitable.

INTRODUCTION

Technology has been revolutionizing industrial sectors for more than 200 years. We have seen the way mechanized production increased productivity during the Industrial Revolution when it replaced workers performing repetitive tasks. We have also experienced the way IT and computing have revolutionized the means by which production is planned, managed, accounted for, inventoried and even delivered. But the divide between the computing haves and have-nots has grown in the past decade, and nowhere has this been a more serious problem than in the manufacturing sector. A recent series of workshops conducted by the National Academy of Engineering highlights why this divide is so important, suggesting that adding value, and thus capturing a higher percentage of that value, means integrating innovation, design, manufacturing and service delivery. This will require a systems-wide view of the innovation-to-production process, and it may favor entrepreneurs. Kate Whitefoot and Steve Olson, authors of a report on the workshops' findings, believe that "there is no better time [than now] to be a talented entrepreneur who can take innovations and scale them rapidly, digitally and globally."

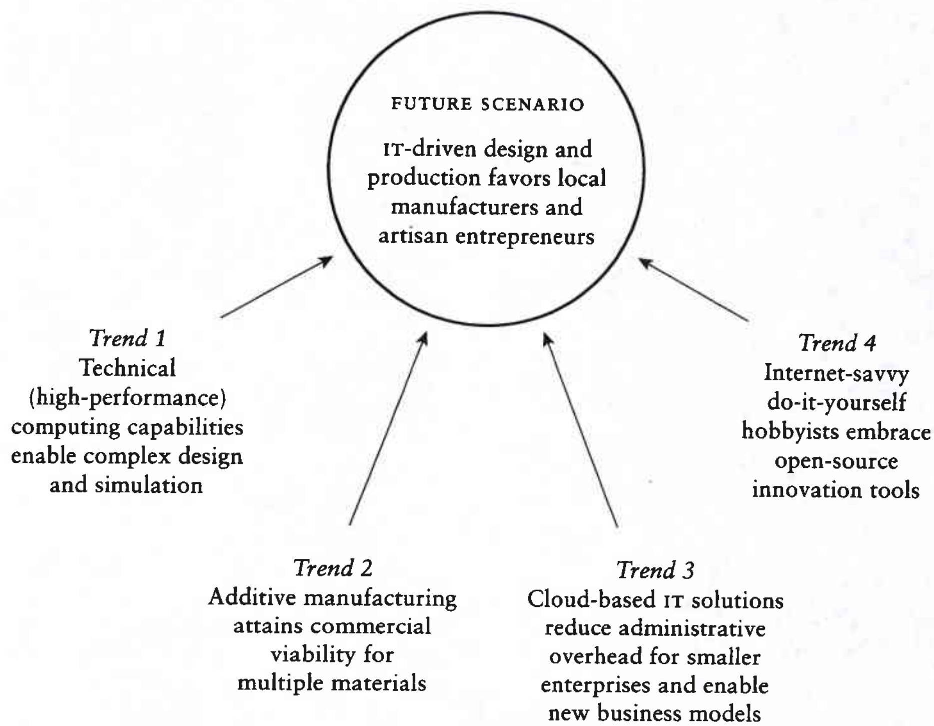
In essence, this chapter presents a story based on predictions about the changes in store for the industrial supply chain, including changes in the relationship between larger original equipment manufacturers (OEMs) and their suppliers. This is also a story about the changing dynamics within current supply chains, where the traditional David-and-Goliath relationships are evolving. If these predictions are borne out, David may triumph over Goliath more frequently in the future, and at least will enjoy the luxury of increased self-determination.

THE POTENTIAL FOR A REVOLUTION IN THE MANUFACTURING SECTOR

Strategic roadmapping[2] has been used successfully to help companies develop scenarios of the future, and the recent growth of *outside-in* thinking[3] emphasizes the importance of sensing and sense-making in the external environment for determining the critical forces that will be game changers. At the heart of this approach lies a need to capture the breezes of today that will turn into the gales of change for tomorrow. But it is rare that a single trend by itself is a disruptive force. Instead, it is the combination of multiple, often seemingly unrelated trends that presents truly disruptive future scenarios.

There are four trends that have the power to revolutionize the manufacturing sector. These four trends suggest that the current arrangement of tiered supply networks based on low-cost production and economies of scale is unlikely to dominate in the future. Instead, IT-driven design and production will favor local manufacturers and artisan-entrepreneurs (FIGURE 1).

FIGURE 1: *Four Trends With the Potential to Revolutionize the Manufacturing Industry*



HIGH-PERFORMANCE COMPUTING CAPABILITIES TAKE SOPHISTICATED MODELING MAINSTREAM

The first trend is related to the increasing availability of high-performance computing capabilities beyond traditional research labs and large manufacturers. Many tools developed over the past two decades that support product-development innovation are well understood in the manufacturing environment, and their combination with automation technologies has transformed the factory floor. CAD/CAM, combined with the capabilities of computer-numerical controlled (CNC) machines, has boosted productivity and is commonplace in most manufacturing firms, regardless of size or sector.

Less well understood by the majority of companies are the tools that support testing, advanced analytics and simulation. Large companies such as Boeing have been designing, simulating and testing digitally for over two decades. The CATIA product-design software developed by Dassault Systemes enabled Boeing engineers and designers to see parts of enginesas solid images and then simulate the assembly of those parts on the screen, easily correcting misalignments and other fit or interference problems. But while the use of modeling and analytics has increased, it is still a relatively rare capability for the typical small or medium-sized enterprise (SME). A study of 232 manufacturers conducted in 2010 by the National Center for Manufacturing Sciences and Intersect360 Research found that 61 percent of companies with over 10,000 employees are using high-performance computing to model their designs digitally, yet only 8 percent of companies with under 100 employees are using this technology.[1] This same study found that the most significant barriers to adoption of high-performance modeling and simulation technologies were lack of internal expertise, the cost of software and, to a lesser extent, the cost of hardware.

To introduce SMEs to the potential of digital modeling and analytics, the National Digital Engineering and Manufacturing Consortium (NDEMC) was created in 2011 by the U.S. Department of Commerce's Economic Development Administration. NDEMC is a regional initiative focused on Midwestern manufacturers and includes partners such as John Deere, Lockheed Martin, General Electric and Proctor & Gamble.

There are currently 20 different ongoing projects in its portfolio that span alternative energy, medical devices, cooling systems and plastics.[5]

The consortium is already helping SMEs. Jeco Plastics is a small custom-mold manufacturer of large, complex and high-tolerance products for large OEMs in the automotive, aerospace, printing and defense industries. The company uses rotational molding and twin-sheet pressure-forming processes and employs materials ranging from commodity thermoplastic resins to highly complex resins with continuous unidirectional carbon fibers.

Recently, Jeco received a last-minute design change for a custom pallet that it was designing for a large German manufacturer. Jeco was able to access high-performance computing resources through NDEMC. Using the center's "ABAQUS" modeling and simulation tool developed by Dassault Systems, Jeco was able to analyze the needed design changes, resulting in a multi-year contract with estimated annual orders of $2.5 million. Under normal circumstances, these high-performance computing resources would have been beyond Jeco's reach due to budget constraints and a lack of modeling and simulation expertise.

Such successes should spawn similar efforts in other regions of the United States. Critical to these efforts will be access to hardware and software, combined with the expertise needed to develop and interpret the analytics and simulations they produce. To date, most manufacturing sectors, and particularly the SMEs within them, have failed to invest in these capabilities.

ADDITIVE MANUFACTURING COMES OF AGE

The second trend that will significantly influence the future of manufacturing is the increasing commercial viability of additive manufacturing, which is also known as "3D printing."[6] This process, involving the layer-by-layer creation of objects, has been used for rapid parts prototyping and small-run production in a variety of industries for more than two decades. But recent developments in its capabilities — the introduction of new machines and their declining costs — have begun to move additive manufacturing into more mainstream part production. Interestingly, low-capability and low-cost machines have begun to engage the interests of designers far beyond traditional manufacturers, a point to be addressed later in this chapter.

Rick Karlgaard, publisher of *Forbes* magazine, has speculated in his "Innovation Rules" column that "3D printing may be the transformative technology of the 2015-2025 timeframe."[7] Similarly, Terry Wohlers, a leading expert in the additive-manufacturing industry, believes that additive-manufacturing technology "could very well have a greater breadth of impact on manufacturing than any other technology in recent history."[8]

While additive manufacturing is, in fact, a digitally based trend in manufacturing that frequently relies on high-performance computing for sophisticated modeling, it deserves to be singled out as a key disruptor in its own right. Additive manufacturing uses computer-generated designs to create "build paths" that reproduce the digital model through consolidation of materials with an energy source. The process typically uses a laser or an electron beam that adds material as it is directed along the build path or can be scanned over a pre-placed layer of material. To date, additive manufacturing has been used with polymers, metals and ceramics.

The principal value of additive manufacturing lies in its potential to lower costs through reduced material usage and machining. Furthermore, the technology enables the design and creation of features that are extremely difficult to construct through traditional processes. From a customization and volume standpoint, additive manufacturing offers extreme flexibility for product differentiation, making it feasible to create highly complex one-off components and products.

In the realm of traditional manufacturing, additive manufacturing has long been used in rapid prototyping to create short-term molds or to develop mock-ups of parts, generally in some type of plastic form. These prototypes were considered precursors to the "real" parts design, which would be produced to tighter tolerances and in the actual final material, which was seldom plastic. But additive manufacturing has continued to move closer to that final production run in industry sectors such as healthcare, where dental and prosthetic devices are being produced with this process for final use, and has been migrating into higher-tolerance and complex materials industries, such as automotive and aerospace.

For example, in November 2012 GE Aviation bought Morris Technologies, a small, privately owned precision-engineering firm. Its specialty? Additive manufacturing. Morris will be developing parts for a range of jet engines, including the LEAP, which is being developed by DFM International. This engine is expected to enter service in commercial airlines in the coming years, and 4,000 units already have been ordered.[9] Morris begins with a digital description of the component and uses laser sintering to build it layer by layer. This process is capable of producing all types of metal parts, including those made of aerospace-grade titanium.

Currently, fused-deposition modeling is the most common additive-manufacturing technology available at the consumer level. This process, one of computer-controlled deposition of melted plastic, is found in recently introduced products for consumers and businesses like the Makerbot, RepRap and Solidoodle. Already, 3D printing has become cost competitive: MakerBot recently introduced a $2,199 3D printer, and costs continue to fall. Jeff Kowalski, CEO of Autodesk, a leading software maker for 3D modeling and printing, notes that the cost of 3D printers has dropped tenfold in five years, "essentially riding the Moore's Law curve, just as 2D printing started doing in the 1980s."[10]

Wohlers has reported that it took the additive-manufacturing industry 20 years to reach $1 billion in size. Sales of additive-manufacturing products and services are predicted to reach $3.7 billion worldwide by 2015 and to surpass $6.6 billion in 2019.[11]

CLOUD-BASED SOLUTIONS REDUCE COSTS, LEVEL THE PLAYING FIELD FOR SMES AND ENABLE NEW BUSINESS MODELS

The third trend that may disrupt current manufacturing-supply-chain practices is the increasing use of cloud-based solutions that can be accessed on an as-needed basis. Cloud computing is likely to enable SMEs to more effectively compete with larger companies because it reduces the cost of accessing sophisticated design, development and enterprise-related business tools. If this trend continues, SMEs will not be hobbled by the prohibitive cost of purchasing and maintaining comprehensive IT systems. The cloud effectively enables both internal decision making and new business models.

From a business-process innovation perspective, information technology improves internal decision making through software that provides support for enterprise resource planning (ERP), material requirements planning (MRP) and supply-chain-management logistics. These types of IT solutions help manufacturers develop a deeper understanding of the needs of their businesses, the flow of their work and the integration of the supplier network into a cohesive solution. While these solutions have typically been used successfully by large companies, SMEs will increasingly be able to take advantage of these enhancements.

In the future, many large-scale, legacy ERP systems will transition to cloud-based solutions. But these new solutions will require a different approach to IT management within the manufacturing environment by using a software-as-a-service (SaaS) deployment model for ERP implementations.

HIAWATHA RUBBER GOES CLOUD-BASED FOR ERP

Based in Minneapolis, Hiawatha Rubber is a family-owned designer and manufacturer of custom-molded rubber parts and assemblies for OEMs. Hiawatha recently replaced an aging, in-house ERP system with a cloud-based ERP solution from Plex Systems, an independent software vendor specializing in cloud-based manufacturing software. While their old system could provide basic information, it lacked the ability to provide the detailed, real-time and accurate financial and manufacturing information that company decision makers needed. This was particularly challenging when they were trying to integrate production data with costing and quality data.

Following a three-month implementation — about half the time it took to install the original in-house system — Hiawatha managers were able to see the value of real-time visibility. According to Tim Carlson, a company manufacturing manager, "the plant-floor employees now see upcoming jobs and where materials are located in real time, enabling them to make quicker and better decisions. Now when a customer calls for a rush order, we can tell them in minutes when their order will be ready, compared with several hours and a significant amount of manual effort when we had our previous system in place."[12]

The company's website proudly advertises this capability, saying: "Our extensive and sophisticated enterprise resource planning system lives in the cloud, giving us a platform that's typically only found at Fortune 500 companies."[13]

Just as the cloud has created new business models in retail, entertainment and journalism, it is doing so in manufacturing, with improved internal visibility, customer-relationship management and the extension of product sales into services. The cloud-based business model allows manufacturing franchises to compete locally and on a smaller scale using Internet-based tools. Drexel Metals is a good example of this emerging model, going beyond the Hiawatha Rubber example to focus on internal company business-process innovation.

DREXEL METALS ESTABLISHES A DISTRIBUTED MANUFACTURING NETWORK SUPPORTED BY WIKIS AND INTERNET TOOLS

In 1985, Drexel Metals was a steel supplier making everything from lighting fixtures to ceiling ribs for the construction industry. But its customers began asking for metal roofing products, where 80 percent of the market is dominated by traditional go-to-market factories selling pre-fabricated roof panels ready for installation. According to company President Brian Partyka, "a challenge with pre-fabricated metal roofing is that when you ship it, you're shipping unwieldy sections that require a lot of packaging to protect them during transport."[14]

Instead, Drexel Metals decided that the best way to get its product to both residential and commercial customers was through a network of specialty installers who could fabricate the "standing-seam" metal roofs onsite. This eliminated expensive shipping and also reduced the lead time necessary for contractors and installers. Now Drexel Metals sells one- to two-ton coiled metal rolls in 36 colors, and it offers installers the ability to buy or lease-to-buy a portable roll-forming machine that can transform these rolls into the specific standing-seam roof desired by the customer. But the company didn't stop there. As a way to support remote fabrication, Drexel developed cloud-based tools and services that enhance their customers' ability to plan for, bid and win sophisticated roofing jobs. In short, through a network of regional manufacturers, Drexel Metals now orchestrates a supply chain that runs from the steel manufacturer to the installed roof. The Drexel Metals Association of Regional Manufacturers provides these machine owners with everything they need to compete with the much larger, traditional, fixed-in-place manufacturers.

Drexel's distributed-manufacturing and -installation model relies heavily on the Internet to provide technical and engineering support. The members of its association are supported by a wiki — a website that allows its users to access, add to and edit its content — that contains more than 2,000 searchable documents describing everything about the product, its installation and the on-site forming of roof sections. In addition, cloud-based costing and bidding tools help potential installers estimate material needs and designs. The design support relies on images captured by Pictometry, a company that uses aerial images to provide precision measurements that are fed to installers via the cloud.

Today, Drexel Metals supports its customers with an anywhere-anytime access strategy that leverages mobile technology. In addition to its wiki, it has a YouTube channel and a LinkedIn group, and it also communicates via Facebook and Twitter. The result of this approach has been phenomenal growth. Revenue went from $24.2 million in 2008 to $51.3 million in 2011, with a three-year overall growth figure of 112 percent. In 2012, Drexel Metals reached number 2,260 on the *Inc. Magazine* 5000 and number 67 on the publication's list of the top 100 manufacturing companies.[15] Similar growth awaits other traditional manufacturers that decide to embrace the cloud.

THE HOBBYIST BECOMES THE PRODUCER

The fourth trend that will influence the future of manufacturing is the rise of IT-savvy Internet hobbyists who are using open-source software tools to design and innovate. As the design and development tools simultaneously become more sophisticated and easier to use, the capabilities that are currently restricted to high-end designers will migrate to less-experienced users, increasing their potential to translate their ideas into realistic and producible products. The decreasing costs and increasing capabilities of additive manufacturing will enable the hobbyists of the future to successfully compete against more-established traditional manufacturers. Chris Anderson, former editor-in-chief of *Wired Magazine*, has termed these hobbyists "makers" and argues that those who own the production technology get to determine what is produced. As these makers grow in number, it is not unthinkable that manufacturing could return to the garage.

Wohlers Associates' most recent statistics support expectations for the rise of the artisan-entrepreneur, as they indicate that recent growth in sales of personal additive-manufacturing systems has been explosive (SEE FIGURE 2). Moreover, Wohlers notes that these systems do not appear to be going to professional or industrial buyers.

FIGURE 2: ***Sales of Personal Additive-Manufacturing and 3D-Printing Systems***

Source: Data from Wohlers Report 2012

In January 2005, *Make Magazine* launched with a goal of encouraging do-it-yourself projects' being undertaken by hobbyists and other small-scale producers. The magazine appears both in print and online, where it hosts blogs and other forums where do-it-yourselfers can communicate with each other.

But it is not just hobbyists and do-it-yourselfers with additive-manufacturing capabilities that are involved in this transformation. For example, Shapeways — a 3D-printing services start-up company that spun out of the Royal Phillips Electronics lifestyle incubator program — is changing the meanings of "producer" and "consumer." Using Shapeways' website, clients can upload product specifications that the company feeds into a 3D printer, which then produces the desired device. In 2011, Shapeways shipped nearly 750,000 parts. Materials choices range from plastic and stainless steel to silver and ceramics, and the company is continuously expanding, most recently opening a 3D-printing-services factory in Queens, N.Y.

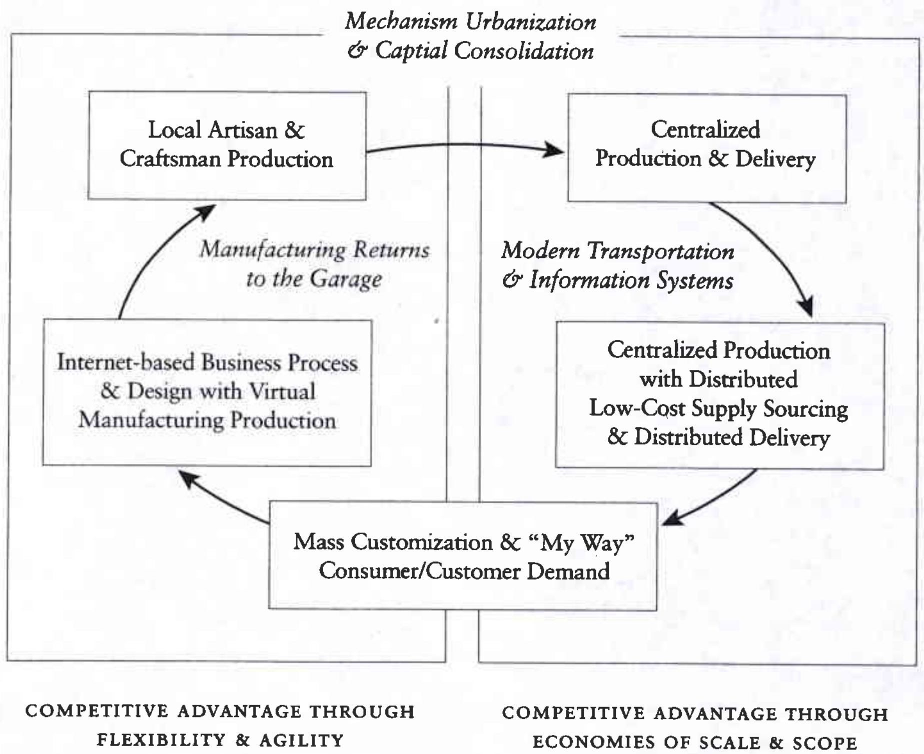
SUPPLY-CHAIN DISRUPTION

Before the Industrial Revolution, production of goods was done by local artisans and craftsmen relying primarily on locally available materials and selling to local customers. With the introduction of mechanization, production became increasingly centralized in factories, where machines replaced people, taking over many repetitive tasks. Factories grew larger as more people moved from rural areas to cities and as capital became more available. Modern transportation and information systems extended centralized production by enabling distributed material sourcing from low-cost suppliers. These modern transportation and information systems also enabled efficient distributed delivery (FIGURE 3). For over 200 years competitive advantage came from economies of scale and scope.

Joseph Pine, author and co-founder of Strategic Horizons LLP, envisioned markets of one, where individuals could set the specifications and purchase exactly what they wanted.[7] While manufacturers to date have not been able to achieve such mass customization, the Internet has created the expectation of individualized and customized experiences, and online tools that let consumers select various product features have become increasingly sophisticated. Today consumers — and industrial customers as well — demand an increasing level of customization, creating an opportunity for those companies that can service the "long tail" — those micro-manufacturers who will make one-off products on an as-needed or as-requested basis.

This is particularly true of the younger, Internet-savvy consumers who listen to playlists of their own choosing, wear clothes and shoes that are

FIGURE 3: *Manufacturing Comes Full-Circle*



designed with their unique feature choices and receive news alerts, shopping alerts and other customized information feeds based on settings they have established on their mobile phones.

In short, society is going from a producer-centric model to a consumer/customer-centric model. When this new form of consumption is combined with advances in additive-manufacturing capabilities, markets of one will be achieved. In this future, artisan-entrepreneurs will use cloud-based design tools to transform ideas into products that can be produced and delivered at the point of demand. Manufacturing truly can go back to the garage in a cost-effective way in a world where the new competitive advantage will come from flexibility and agility. In this future, the same capital-intensive equipment, factories and distribution systems that were once barriers to entry will become barriers to change. FIGURE 4 summarizes the challenges and enablers in this new future, where mass customization and "My Way" consumer/customer demand will be met through virtual-manufacturing environments that displace supply chains as we know them today.

FIGURE 4: *Virtual Manufacturing Environments Displace Traditional Supply Chains for Customized & Localized Manufacturing & Delivery*

MASS CUSTOMIZATION & "MY WAY" CONSUMER/CUSTOMER DEMAND

DESIGN CHALLENGES	BUSINESS PROCESS CHALLENGES	PRODUCTION CHALLENGES
• Modeling • Simulation • Testing	• Order Taking • Costing & Bidding • Tracking • Delivery	• Material Sourcing • One-off Manufacturing • Material Handling • Scaling
↓	↓	↓
ENABLERS	**ENABLERS**	**ENABLERS**
• High-Performance Computing • Broadband Access	• Cloud Computing • Software as a Service	• Additive Manufacturing

Supply chains will change in at least four ways:

1. Product innovation and manufacturing innovation will become tightly coupled;
2. Decentralized production and distribution will become localized to the assembler or consumer location;
3. Artisan-manufacturers producing customized products will compete successfully with established OEMs; and
4. Current logistics practices that emphasize efficient transfer of materials within the factory and between companies along the supply chain will become obsolete in many sectors.

Exactly when will this occur? It depends on development of an underlying infrastructure for additive manufacturing that can enable high-quality, high-tolerance production of complex materials at an affordable price. This infrastructure must include such things as design guidelines, economic models and metrics to assess and predict resultant microstructures and their effects on the products' properties and characteristics. A recent Atlantic Council Strategic Foresight Report describes how additive manufacturing is advancing simultaneously at the high end and at the low end. The report notes that, "While these two technical streams will continue to develop separately — with seemingly opposing end goals — we can expect to see a convergence, in the form of a small-scale direct metal 3D printer."[18]

CONCLUSION

Ultimately, if these predictions prove correct, there will be a transition from supply chains to supplier ecosystems, a localization of suppliers who are moving up the value chain closer to the consumer, and a renaissance of artisan manufacturing where individual firms armed with new technologies are truly able to deliver the mass customization that Joseph Pine predicted more than two decades ago. Centralized mass-production operations will continue to exist, but their dominance and growth will no longer be a foregone conclusion.

In this future, IT expertise will be essential for manufacturers to compete successfully — both locally and globally. Broadband communication and the ability to access high-performance computing will be a critical skillset in designing and creating new products in the evolving supplier ecosystems. And this same IT expertise, when combined with emerging additive manufacturing, will enable the long tail.

Unfortunately, this future will come at a price. Manufacturers with an installed base of capital equipment, large-scale factories and extensive long-term contracts with existing suppliers will find themselves up against very agile and flexible smaller competitors. Having an extensive installed base will go from being a competitive advantage to being a competitive disadvantage. Instead of being a barrier to entry, a significant installed base will become a barrier to change.

But the beauty of this future is that design can happen anywhere, innovation can happen anywhere and production can happen anywhere. The current wage-rate differentials between developed and developing nations become less important. Instead, access to consumers and key producers becomes the force that dictates where desired production sites are located.

In this future, innovators and designers have a key advantage. Understanding what the consumer wants and needs, designing the corresponding product and then enabling its production anywhere in the world where there is adequate additive-manufacturing capability fractures the current view of the supply chain.

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