The Future of Manufacturing

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Abstract

At its heart, this chapter presents a story about the future of manufacturing. This story is based on predictions about the future. Specifically, that (1) increasingly firms of all sizes will have access to high performance computing capabilities that will enable sophisticated modeling and simulation, (2) additive manufacturing will become commercially competitive across a wide range of industry sectors and will support the use of multiple materials, and (3) new business models that rely on IT will reduce the administrative overload of bidding, winning and delivering products and services. Together these combine to favor localization of manufacturing rather than today's more centralized, economies-of-scale production models. A fourth trend – a rise in the number of hobbyists who become producers of one-off and small lot products – will change the definition of a "manufacturer" and may, in fact return manufacturing to the garage. An information-technology driven transformation in the manufacturing sector is inevitable.

Introduction

Predicting the future based on changes in technology is not novel. Technology has been revolutionizing industry sectors for decades. We have seen the way that mechanized production increased productivity by replacing workers for repetitive tasks during the industrial revolution. We have also experienced the way that information technology and computing have revolutionized the way that 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 no where has this been a more serious problem than in the manufacturing sector. A recent series of workshops conducted by the National Academy of Engineering (Whitefoot and Olson, 2012) highlights why this divide is so important, suggesting that to add value (and thus capture a higher percent of that value) means that innovation, design, manufacturing and service delivery must be integrated. This will require a systems view, and may actually favor entrepreneurs. "There is no better time to be a talented entrepreneur who can take innovations and scale them rapidly, digitally and globally" (Whitefoot and Olson, 2012, p. 11).

In short, this chapter presents a story about the changing nature of the supply chain and the relationship between larger original equipment manufacturers (OEMs) and their suppliers. It is also a story about the changing dynamics within current supply chains, where the traditional David and Goliath relationships will evolve. If, in fact, these predictions come to pass, David may triumph over Goliath more frequently, and at least will have the luxury of increased self-determination.

The potential for revolution in the manufacturing sector

Strategic roadmapping (Petrick & Martinelli, 2012) has been used successfully to help companies develop scenarios of the future and the recent movement toward *outside in* thinking (Day and Moorman, 2010) emphasizes the importance of sensing and sense-making in the external environment to determine the critical forces at work that will be game changers and thus future shapers. At the heart of this approach lies a need to capture the *whispers* 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 present truly disruptive future scenarios. This section introduces 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. See Figure 1.

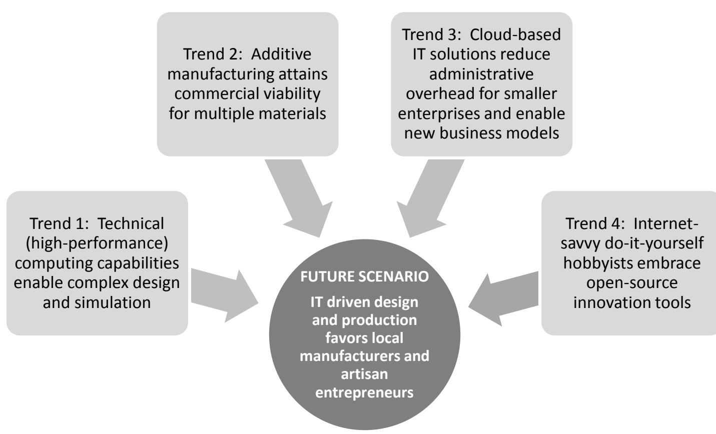

Figure 1: Four trends with the potential to revolutionize the manufacturing industry

Technical (high performance) computing capabilities take sophisticated modeling mainstream

The first trend is related to the increasing availability of technical (high performance) computing capabilities beyond the traditional research labs and very large scale manufacturers. Many tools that support product development innovation are well understood in the manufacturing environment as automation has transformed the factory floor in the past two decades. CAD/CAM combined with the capabilities of CNC machines have boosted productivity and are 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. CATIA, developed by Dassault Systemes enabled Boeing engineers and designers to see parts as solid images and then simulate the assembly of those parts on the screen, easily correcting misalignments and other fit or interference problems. While the use of modeling and analytics has increased, it is still a relatively rare capability for the typical SME. The National Center for Manufacturing Sciences (NCMS) and Intersect360 Research conducted a study of U.S. manufacturers in 2010. Of the 232 responding companies, 61% of companies with over 10,000 employees are using high performance computing to model their designs digitally (Feldman, 2011). Yet only 8% of companies with under 100 employees are using this technology. This same study found that the most significant barriers to adoption were lack of internal expertise, the cost of software and, to a lesser extent, the cost of hardware.

To introduce 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 Economic Development Administration. NDEMC is focused on Midwestern manufacturing SMEs and includes partners such as John Deere, Lockheed Martin, General Electric and Proctor and Gamble. There are currently 20 different projects on-going that span alternative energy, medical devices, cooling systems, plastics and others. NDEMC touts Jeco Plastics as one of its success stories (Kirkley, 2012).

Jeco Plastics Leverages High Performance Computing

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 materials range from commodity thermoplastic resins like polyethylene to highly complex resins such as polyetherketoneketone with continuous unidirectional carbon fibers.

Recently, Jeco received a last minute design change by a large German OEM for a custom pallet Jeco was designing. Jeco was able to work with experts through the NDEMC and to access high performance computing resources. Using ABAQUS modeling and simulation, Jeco was able to analyze the needed design changes, resulting in a design win for Jeco. This directly led to a multi-year contract with estimated annual orders of $2.5 million. Under normal circumstances, the high

> performance computing resources needed would have been impossible due to budget constraints, in part, and also due to a lack of modeling and simulation expertise.

While the Jeco Plastics story is part of a demonstration project though a government-industry partnership, these successes should spawn similar efforts in other geographies. Critical to the success of these efforts will be the access to hardware and software, combined with the expertise needed to develop and interpret the analytics and simulations. To date, most manufacturing sectors, and particularly the SMEs within them, have not been investing 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.[1] Often also referred to as "3D printing," this process is the layer-by-layer creation of objects. This process has been used to do rapid prototyping and small-run production in a variety of industries for over two decades, but recent developments in the capabilites of this process, the development of new machines and the decline in costs of these machines has 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 addressed later in this chapter.

Rick Karlgaard, Forbes Magazine publisher, noted in his Innovation Rules column that "3d printing may be the transformative technology of the 2015-2025 timeframe" (Karlgaard, 2011). 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" (Wohlers, 2012, p. 14).

While additive manufacturing is a digitally based trend in manufacturing that frequently relies on high performance computing for sophisticated modeling, it deserves to be singled out in its own right as a key disrupter. 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 can be directed along the build path with the addition of material or can be scanned over a

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[1] The terms *3D printing* and *additive manufacturing* are often used interchangeably. Additive manufacturing has been used to describe the layer-by-layer joining of materials based on 3D digital models. Recently the popular press has referred to this as 3D printing, a term that is gaining acceptance. Currently, additive manufacturing is used to describe high end production in such areas as aerospace and automotive using industrial systems which typically cost between $5,000 and $25,000 (but can top out at nearly $1million) while 3D printing refers to production on machines below $5,000. The distinction between the two is unlikely to continue into the future, however, as the capabilities at the high end and the low end converge over time.

preplaced layer of material representing a powder bed. To date, additive manufacturing is used for polymers, metals and ceramics, and the most common use involves polymers.

The value of additive manufacturing is its potential to reduce costs through reduced material usage and machining. Moreover, additive manufacturing 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 for 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" part design which would be produced to tighter tolerances and in the actual final material, which was often not 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 migrating into even higher tolerance and complex materials industries such as automotive and aerospace applications.

For example on November 20, 2012 GE Aviation bought Morris Technologies, a privately owned small precision engineering firm. It's speciality? – additive manufacturing. Morris will be developing parts for a range of jet engines, including the LEAP jet engine which is being developed by DFM International, expected to enter service in the coming few years (The Economist, 2012). Already 4,000 engines have been ordered. 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 is a process that is computer controlled deposition of melted plastic and is found in products like the Makerbot, the RepRap and Solidoodle among others. Already 3d printing has become cost competitive. MakerBot recently introduced a $2199 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" (Kowalski, 2011).

Wohlers Associates reported that it took the additive manufacturing industry 20 years to reach $1billion in size. Sales of additive manufacturing products and services are predicted to reach $3.7billion worldwide by 2015 and to surpass $6.6billion in 2019 (Wohlers, 2012, p. 131).

Cloud-based solutions reduce costs, level the playing field and enable new business models

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

From a business process innovation perspective, IT improves internal decision-making through software that provides enterprise materials and resource planning (MRP and ERP) support, supply chain management logistics support and customer relationship management. 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. These new solutions will require a different approach to IT management within the manufacturing environment, however, using a software-as-a-service (SaaS) deployment model for ERP implementations.

Hiawatha Rubber Goes Cloud-Based for ERP

Based in Minneapolis, MN, Hiawatha Rubber is a family-owned designer and manufacturer of custom molded rubber parts and assemblies for OEM manufacturers. 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 ERP systems. While their current system could provide basic information, it lacked the ability to provide the detailed, real-time and accurate financial and manufacturing information company decision-makers needed. This was particularly challenging when 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 decision-makers were able to see the value of real-time visibility. According to Tim Carlson, a 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" (Baker Tilly).
>
> The company's website proudly advertises this capability saying "Our extensive and sophisticated enterprise resource planning (ERP) system lives in the cloud, giving us a platform that's typically only found at Fortune 500 companies" (Hiawatha Rubber).

But the cloud is not only improving internal visibility and decision-making. It is also enabling new business models. We are already seeing new business models in retail as online sales compete with bricks-and-mortar establishments, in entertainment as Internet distribution replaces traditional movie and television distribution channels, and in media as blogs, wikis and online news sources disrupt print media. Manufacturing companies have long believed that IT enabled business models were centered around customer relationship management and the extension of product sales into services.

Today there is a growing trend that enables a cloud-based business model where manufacturing franchises can compete locally and on a smaller scale using Internet based tools. This trend goes beyond the Hiawatha Rubber example noted earlier which focused on internal company business process innovation. Drexel Metals is a very good example of this emerging business model.

Drexel Metals Establishes a Distributed Manufacturing Network Supported by Wikis and Internet Tools

In 1985, Drexel Metals considered itself to be a steel supplier making everything from lighting fixtures to ceiling ribs for the building and 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 and then shipped standing seam roof panels ready for installation. According to Brian Partyka, president of Drexel Metals, "a challenge with prefabricated metal roofing is that when you ship it, you're shipping unwieldy sections that require a lot of packaging to protect them during transport" (Partyka, 2012). Instead, Drexel Metals decided that the best way to get its product to end residential or commercial customers was through a network of specialty installers who could fabricate the standing seam metal roofs on-site. This eliminates expensive shipping and also reduces the leadtime necessary for contractors and installers. Drexel Metals sells 1-2 ton coiled metal rolls in 36 colors, and 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 profile desired by the customer. But Drexel Metals 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, bid and win sophisticated roofing jobs. In short, through a network of regional manufacturers, Drexel Metals orchestrates a supply chain from the steel manufacturer to the installed roof. The Drexel Metals Association of Regional Manufacturers (DM-ARM) 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. DM-ARM members are supported by a wiki that contains over 2000 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 the wiki, Drexel Metals has a YouTube channel and a Linkedin group, and it communicates via Facebook and Twitter. A result of this approach has been phenomenal growth at Drexel Metals: 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 No. 2,260 on the Inc. Magazine 5,000 and No. 67 on the publication's list of the top 100 manufacturing companies (Inc, 2012). Similar growth awaits other traditional manufacturers that decide to embrace the cloud.

The hobbyist becomes the producer

The forth 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 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 actually translate their ideas into realistic and producible products. Combined with the decreasing costs and increasing capabilities of additive manufacturing, hobbyists of the future will be able to successfully compete against more established traditional manufacturers. Chris Anderson (2012) 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 numbers, it is not unthinkable that manufacturing could return to the garage.

Wohlers Associates' most recent statistics support the likelihood of the rise of the artisan entrepreneur, indicating that the growth of sales of personal systems has been explosive (See Figure 2). Moreover, Wohlers Associates notes that these personal systems do not appear to be going to professional or industrial buyers.

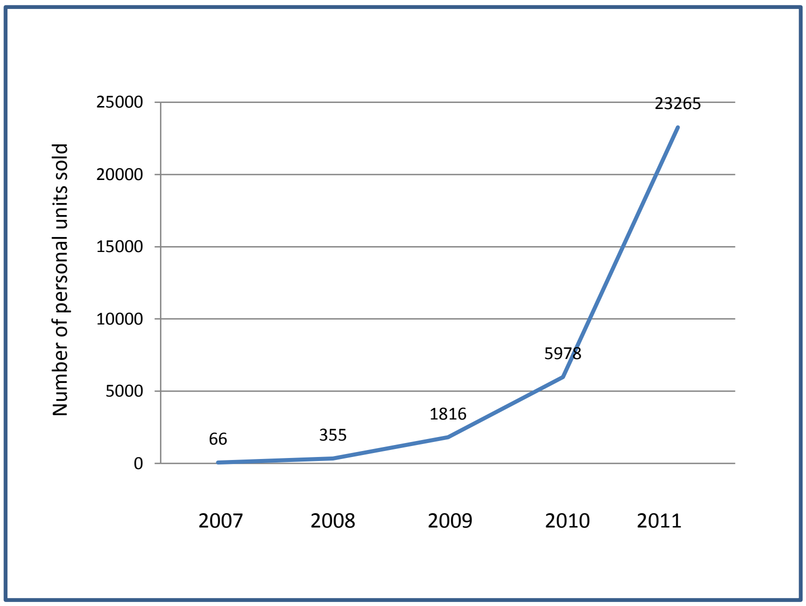

Figure 2: Sales of personal additive manufacturing & 3D printing systems (Source: Data provided in Wohlers, 2012, p. 137)

In January 2005, Make Magazine (and its companion makezine.com) was introduced to support do-it-yourself projects undertaken by hobbyist and others interested producing things. Makezine.com also provides blogs and other forums where do-it-yourselfers can communicate with each other.

It is not just hobbyists and do-it-yourselfers with additive manufacturing capabilities that are involved in this transformation. For example, Shapeways is changing the meaning of producer and consumer through their platform that allows a consumer to upload their product specs to the Shapeways website and then Shapeways uses 3D printing to produce the desired device. In 2011, Shapeways shipped nearly 750,000 parts. Material choices range from plastic to stainless steel, silver and ceramics and are continuously expanding.

Supply chain disruptions

Before the Industrial Revolution, production of goods was done by local artisans and craftsman, 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 for 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 based on low-cost suppliers. These modern transportation and information systems also enabled efficient distributed delivery (See Figure 3). For over 200 years, competitive advantage came from economies of scale and scope.

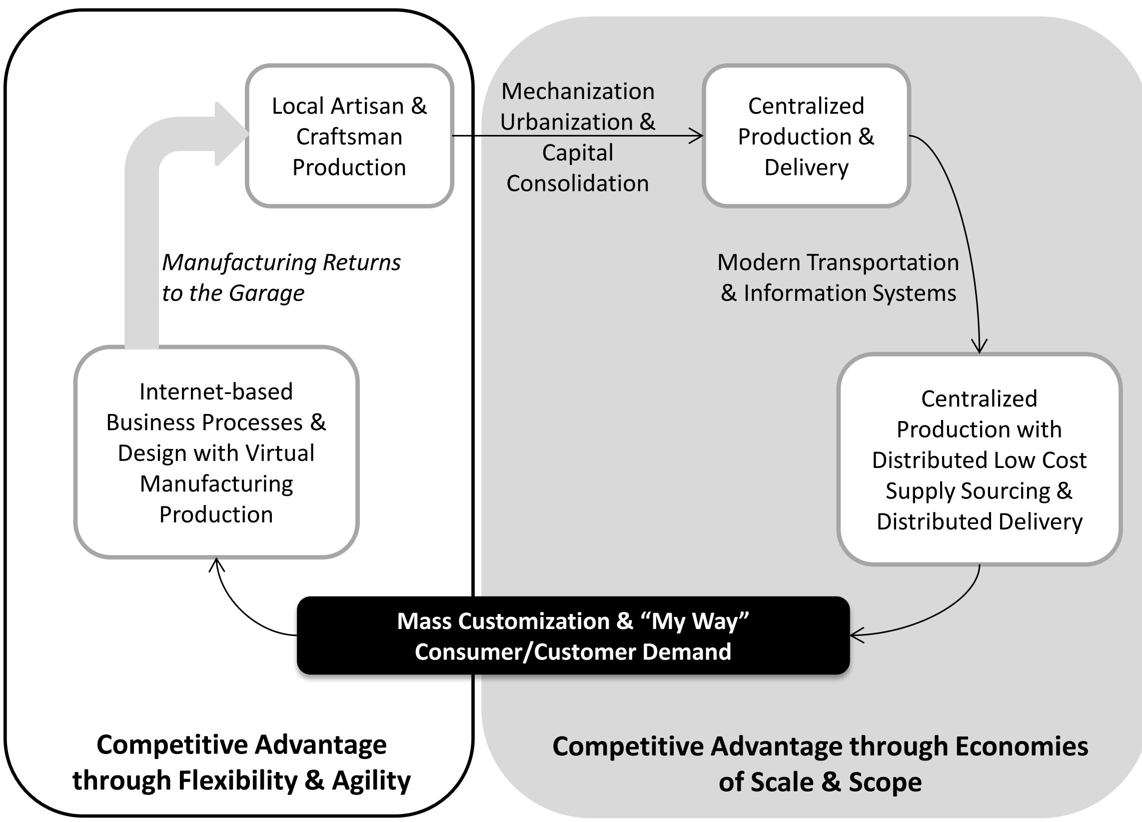

Figure 3: Manufacturing comes full-circle

Pine (1993) envisioned markets of one where individuals could purchase exactly what they wanted that conformed to their specifications. While manufacturing capabilities to date have not been able to achieve such mass customization, the Internet has created the *expectation* of individualized and customized experiences. On-line tools that let consumers select various product features have become increasingly sophisticated. Today consumers (and industrial customers) demand an increasing level of customization, creating an opportunity for those companies that can service the "long tail." This is particularly true of the younger Internet savvy consumers who listen to playlists of their own choosing, wear clothes and shoes that are designed with their unique feature choices, and who are receiving news alerts, shopping alerts and other customized information feeds based on settings they have established on their mobile phones. In short, we are going from a producer centric model to a consumer/customer centric model. When this is combined with advances in additive manufacturing capabilities we will truly achieve markets of one. In this future, artesian entrepreneurs 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 where the new competitive advantage will come from flexibility and agility. In this future, the very 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 the traditional supply chains as we know them today.

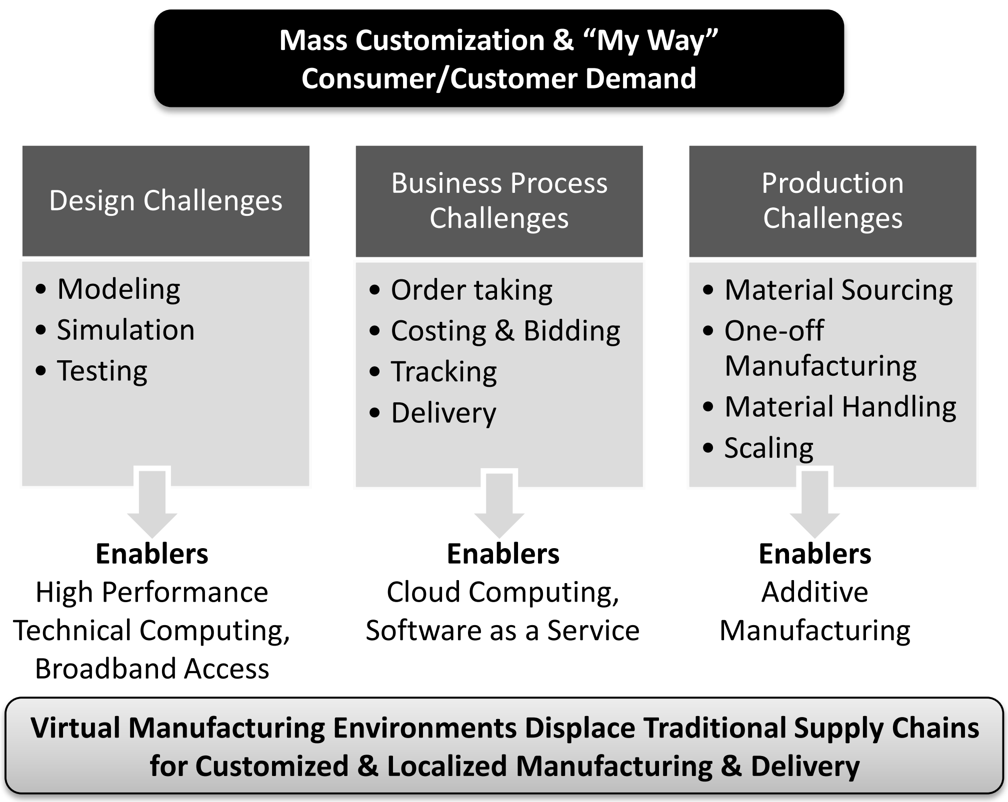

Figure 4: Challenge and enablers to supply chain transformation

Supply chains will change in at least four ways:

1. Product innovation and manufacturing innovation become tightly coupled;
2. Decentralized production and distribution becomes localized to the assembler or consumer location;
3. Artisan manufacturers producing customized products can compete successfully with established OEMs who produce goods through high volumes using economies of scale production models; and
4. Current logistics practices which emphasize efficient transfer of materials within the factory and between companies along the supply chain will be obsoleted in many sectors.

Exactly when will this occur? It depends on the development of the underlying infrastructure for additive manufacturing to enable high quality, high tolerance production of complex materials at an affordable price. This includes things like design guidelines, economic models and metrics to assess and predict resultant microstructures and their effects on the product's properties and characteristics. A recent Atlantic Council Strategic Foresight Report suggests that additive manufacturing is actually simultaneously advancing at the high end and at the low end. "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 …" (Campbell, Williams, Ivanova and Garrett, 2011, p. 5).

Conclusion

Ultimately if these predictions come to pass and can be leveraged, we will see 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 Pine (1993) predicted more than two decades ago. Manufacturing may actually go back to the garage.

This view of the future of manufacturing purposefully takes a positive stance which favors the rapid growth of artisan entrepreneurs and the increased competitiveness of small to medium sized manufacturers relative to their larger competitors. The reality is likely that mass customization and mass production will coexist, depending on sector and product.

The implications of this future are that IT expertise will be essential for manufacturers to compete successfully – both locally and globally. Broadband communication and the ability to access technical computing will be a critical skillset in designing and creating new products in the evolving supplier ecosystems. Interestingly, this same IT expertise, when combined with emerging additive manufacturing, will enable the long tail – those micro manufacturers who will make one-off products on an as needed or as requested basis.

Unfortunately, this future comes 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 competing against very agile and flexible smaller competitors. In point of fact, 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.

The beauty of this future is that design can happen anywhere; innovation can happen anywhere; and production can happen anywhere. In this future, 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.

Also in this future, innovators and designers have a key advantage. Understanding what the consumer wants and needs, designing it, and then enabling the production of this good *anywhere in the world where there is adequate additive manufacturing capabilities* fractures the current view of the supply chain. Supply chains will go from being predictive links of increasing value add to delivery nodes.

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