MIT CTL WHITE PAPER
TRANSFORMING THE FUTURE OF SUPPLY CHAINS THROUGH DISRUPTIVE INNOVATION
ADDITIVE MANUFACTURING

BY KEN COTTRILL
GLOBAL COMMUNICATIONS CONSULTANT
MIT CENTER FOR TRANSPORTATION & LOGISTICS

SPRING 2011
CONTENTS

Executive Summary...........................................................................................................................................3
Introduction.............................................................................................................................................................4
Limited Runs.........................................................................................................................................................5
Scaling Up..............................................................................................................................................................6
Changes By Design............................................................................................................................................7
Looking Farther Ahead....................................................................................................................................8
Flexible Networks...............................................................................................................................................9
Unclear Path.......................................................................................................................................................12
Next Steps...........................................................................................................................................................12
Executive Summary

Additive manufacturing (AM) is the umbrella term for technologies that fabricate products by building up thin layers of materials from three-dimensional, computer-aided designs. A subset of these technologies, 3D printing builds objects on machines that “print” successive layers of materials such as molten plastic.

3D printing has evolved rapidly over recent years. Now it is being used to create product prototypes and to manufacture certain specialized items. From a supply chain perspective, however, the most exciting applications are in finished product manufacturing, where the technology is slowly gaining ground.

If 3D printing becomes a common feature of large-scale manufacturing operations, the technology will have a huge impact on all phases of supply chain management. Companies will find it much easier and more cost-effective to make customized items in limited quantities. Global networks of 3D printing installations will give enterprises the ability to respond rapidly to shifts in market demand and to introduce new products quickly and inexpensively.

More versatile design processes could unleash a new wave of product innovation. In the longer term, the technology has the potential to redefine traditional manufacturing methods. The concept of making products in large, complex plants could become outmoded as companies adopt the more flexible AM model.

This white paper is part of a series of papers published by the MIT Center for Transportation & Logistics (MIT CTL) on disruptive technologies that could reshape supply chains over the next decade.
What if you could click the printing function on your computer and instead of a paper sheet being disgorged from the inkjet printer, a three-dimensional product prototype started to take shape? Unlikely as it may seem, this is a routine operation for companies that use 3D printing, a technology many see as a precursor to a new industrial revolution.

3D printing is part of the AM family of technologies that makes objects from computer models by adding successive layers of materials, hence the “additive” descriptor. Traditional production methods, such as machining, subtract material when fabricating products.

In the 3D printing process, a digital file of the computer-aided design is sent to a printer that creates the object by depositing successive layers of materials a few microns in thickness. Each layer is a cross-section of the object. The “ink” from which items are fabricated is formed in various ways. Metal powder is treated with a laser beam to turn it into a stream of material, or filaments of molten plastic are used, for example.

The technology is less wasteful than traditional production methods where items are injection molded or formed from a block. Since each object is sculpted individually, 3D printing offers great potential for customization and short-run production. Moreover, it dramatically lowers the cost of entry into markets, because new products can be made in limited quantities without the need to make major investments in new tooling.

Although 3D printing has been around since the 1990s, until fairly recently it was more of a curiosity than a commercial proposition. As more efficient machines have emerged, 3D printing has started to take off as a bona-fide manufacturing process. The range of materials used – which already includes ceramics, composites, metals, and plastics – is expanding, and printer prices are coming down.
Limited Runs

Current industrial applications of 3D printing are largely confined to markets for customized, short-run items, such as dental products, hearing aids, and jewelry. There is also a thriving consumer market served by specialist outlets, such as production shops that print objects from customer designs.

An important market for the technology is product prototypes. Companies are using 3D printing to create models of new or modified designs in a fraction of the time it takes using conventional methods such as service bureaus. Moreover, the process is being used in international operations.

“US designers with manufacturing facilities overseas are putting our machines in both facilities so people on both sides are looking at the same object,” says Scott Harmon, Vice President, Business Development, Z Corporation, a manufacturer of 3D printing machines based in Burlington, MA.

Digital prototyping compresses the design cycle, an important plus in markets such as fashion apparel where demand shifts quickly and time-to-market is a key competitive weapon. “Our customers are trying to get to market faster with products that better fit their customers’ needs,” agrees Harmon.

British shoe manufacturer Clarks is using Z Corporation equipment in this way and, according to the company, has cut weeks – and in some cases months – from its design process. Clarks prints one or two physical 3D models per day. “The technology can now...
produce more complex prototypes,” says Harmon, and he sees significant growth in this market.

A much bigger prize in global terms is large-scale, production-grade operations. The major question, therefore, is whether AM will become a primary source of finished products; and, if so, when this is likely to happen.

The question has huge supply chain implications. Additive fabrication processes such as 3D printing provide a fast, flexible, and low-cost alternative to traditional production methods. If these processes eventually replace established, factory-based manufacturing models, companies will have to rethink their global distribution strategies.

**Scaling Up**

Many believe that AM technology – and notably low-cost 3D printing – will enter the manufacturing mainstream. “We are moving in that direction,” says Terry Wohlers, a consultant based in Fort Collins, CO, who specializes in the AM industry. “Machines are getting bigger and faster, and they produce good quality in terms of dimensional accuracy and mechanical properties.”

A profile of the technology published by *The Economist* this past February describes how the European defense and aerospace group EADS is using 3D printers to make landing-gear brackets for aircraft. The aerospace company has plans to develop machines that can print an entire aircraft wing, according to *The Economist*.

Already, AM is being used to produce “custom, limited-edition, and, in some cases, full production items,” says Wohlers. “This activity is expected to increase significantly over the next several years,” he adds. “These applications fit best where production volumes are relatively low, and the product cost or value and complexity are relatively high.” He believes that mass manufacturing involving production runs of millions or tens of millions of units is a far more distant goal.
The technology will bring new opportunities for product customization over the next three to five years, notes Dr. Keith Ulrich, Head of Research & Innovation Management at the global logistics services provider Deutsche Post DHL. A mobile phone might still be made in China, for example, but the casing could be fabricated closer to end markets in Germany and the United States by using 3D printing, he suggests.

**Changes by Design**

The way products are designed could also undergo dramatic change over the next few years as a result of cutting-edge research in the AM field.

“Instead of looking to improve the efficiency of the technology, we are trying to facilitate a completely new way of thinking about design,” says MIT Assistant Professor Neri Oxman, Director of the MIT Media Lab’s Mediated Matter research group. Conventional design approaches start with a form such as a cell phone, a piece of furniture, a house, or even a street. Additive fabrication then turns this form into an object from computer model data. “The 3D form is pre-conceived and only then is it fabricated. I am trying to reverse that process,” explains Oxman. The solutions come from “bio-inspired” structures.

An example is the way in which the human body reengineers bone structures in response to changes in the external environment. When astronauts go into outer space, they lose about 10% of their bone mass after a few weeks as their bodies adjust to a zero-gravity world. “The innate intelligence of the bone varies its density in response to the new load,” Oxman explains.

The MIT researchers have mimicked this intelligence to develop a new product design process. In the traditional method, structural members such as concrete beams are made by filling a mold with the material. The result is a beam made of concrete that is homoge-
neously distributed throughout the member. Oxman is developing a variable-density 3D printer that forms a concrete beam with different densities according to changes in the load across the structure.

The same principle can be used to vary a range of properties such as elasticity, and there are limitless applications in other markets. “We are extracting principles from the natural environment and translating them into additive manufacturing technologies to support a more sustainable approach to design,” she explains. In the case of the concrete beam, it is possible to make a more functionally efficient structural support with less material.

According to Oxman, the lab work to develop the variable-density 3D printing process should be complete in about two years. A possible refinement during that time is to integrate printing machines with analysis software and materials’ mixing chambers. The intention is to change the properties of finished items on the fly. By altering the mix of materials, the same machine could be used to make product variants, for example, versions of a product for uses in different temperatures.

Other advances in the pipeline will take the technology even further. As Oxman points out, the problem with existing AM applications is that “you are using non-traditional, groundbreaking technologies in conservative, traditional ways.”

Looking Farther Ahead

One of the longer-term concepts is using 3D printing to build “intelligent” products that react to changes in the operating environment. This is possible when working with smart, responsive materials such as carbon nanotubes, says Oxman. “We are working on 3D printing walls that breathe by opening and closing pores for example,” she explains. This is a 10-year vision, but Oxman is confident that it can be realized.
Another possibility is creating “swarms” of 3D printers. Again, the inspiration comes from Mother Nature. Termite mounds are huge structures built by tiny organisms working together. The idea is to connect networks of 3D printers to build large assemblies without the need for printers that are equivalent in size. The machines could be reconfigured to construct other products.

When viewed on a broader, more global canvas, AM technology has the potential to spark a new industrial revolution, where established methods for making and delivering products are largely obsolete. “Over the next decade and beyond, the suite of additive fabrication technologies – with 3D printing leading the way – could evolve into a new manufacturing platform where product information is beamed to AM nodes across the globe,” says Ulrich.

In this world, the concept of a sprawling factory that spits out large volumes of items could be replaced by networks of small, nimble production shops that tailor products to customer demand. “Almost anyone located anywhere can become a manufacturer, even though they do not have a machine on-site,” says Wohlers. The basic requirements are some creativity and the ability to market designs and process orders on the Web. “It is a different way of thinking about manufacturing,” he says.

In this environment, the laws of economies of scale do not hamper innovation because market-entry costs are generally low, and it is economically feasible to make products in small batches. Ultimately, the production shop might be the individual consumer. PropONENTS of the technology believe that, in the longer term, consumers equipped with 3D printers will be able to customize a product, download a file from the seller, and print the item at home.

Flexible Networks

Perhaps not surprisingly, AM methods are attracting interest from leading lights in the supply chain community. “As the price points
come down and the quality improves, 3D printing will be very intriguing to us across a number of different segments,” says Joseph Guerrisi, Vice President, New Product Development, in the Atlanta office of global logistics company UPS. “3D printing will have a huge impact on the logistics industry,” says Ulrich. DHL explored the future of the technology and saw demonstrations of 3D printing at an event that it organized in 2010.

Shipping product prototypes is a market served by third party logistics providers (3PL) that could be threatened by 3D printing. The need to expedite models to design and marketing teams around the world would diminish if more companies set up printers in satellite locations. But the real breakthrough in the supply chain domain is the arrival of 3D printing as a serious competitor in finished product markets. Guerrisi believes that the technology is slowly gaining acceptance in applications that are “taking it from the prototype to the production-grade stage for smaller components.”

The potential changes are many. Here are a few possibilities.

3PL to Manufacturer 3PL

A new type of 3PL could emerge that offers manufacturing services through 3D printing. “From a UPS standpoint, we are asking, ‘Where do we play?’” in the unfolding market for AM-based manufacturing, says Guerrisi. A possible answer is as a manufacturing and distribution hub. Operators like UPS are well positioned to take on this role because a number of intellectual property issues must be resolved before AM methods become ubiquitous.

As a trusted third-party provider, UPS has the market stature and scale to function as a new type of hub where products are made, assembled, and distributed. “We are the connection point between the final customer and the production company,” agrees Ulrich. “This will be a very interesting position for logistics companies.”
A New Breed of Agile Supply Chains

With 3D printers operating as standalone installations in strategic locations, companies could manufacture in short runs at multiple sites across the globe. The networks would flex with shifts in demand by reconfiguring the manufacturing nodes or by adjusting machine outputs. Production units shift rapidly from one product variant to another without the need for retooling or lengthy line delays.

The AM model also offers tremendous opportunities to cut inventory costs, because there would be less need for inventory. The management of raw materials inventory also would be streamlined as production processes generate less waste.

Streamlined Maintenance

Armed with 3D printing, machine repair services “don’t have to have every single component; you can print components when needed,” says Ulrich. Positioning parts inventories would become much less of a challenge for teams in the field. Ulrich believes that this is another service that 3PLs could provide. Similarly, remanufacturing is easier when specific components can be made almost immediately.

Extreme Just-in-Time

A flexible, highly adaptive network of 3D printing installations could take just-in-time and postponement operations to new levels of efficiency. AM methods could be used to produce precise quantities of customized components very late in the final production cycle when more accurate demand information is available, for example. “It will have a big impact on demand forecasting,” observes Ulrich, as companies use the technology to achieve closer alignment between their manufacturing operations and customer demand.
New Risk Management Dimensions

Opportunities for improving risk management represent another potential benefit of AM-based manufacturing. Low market-entry barriers and the ability to retool quickly reduce business risk. The technology also provides companies with a rapid-response mechanism when an unforeseen incident disrupts the supply chain.

Green Premium

Since additive fabrication is less wasteful than traditional production processes, it reduces carbon footprints. Similar benefits accrue from innovations such as Oxman’s revolutionary design processes that increase functional efficiency, while reducing material content.

Unclear Path

AM is gaining ground as a fully fledged manufacturing process. It is likely that, over the next five years, the technology will be used more widely to produce components and to supplement the output of mass-market production lines.

Its future as a mainstay manufacturing process is less clear, but technologies such as 3D printing have the potential to redraw the manufacturing map. Much depends on how these methods evolve over the next decade. “The big turning point is when we are talking about production-ready materials,” says Guerrisi. “That is a number of years away – but when it happens, this will be a different race.”

Next Steps

MIT CTL is exploring potential supply chain applications for a number of cutting-edge technologies. For more information, contact: Jim Rice, Deputy Director, MIT CTL, at email: jrice@mit.edu.
ABOUT US

About the MIT Center for Transportation & Logistics: MIT CTL has been a world leader in supply chain management research and education for more than three decades. Combining its cutting-edge research with industry relationships, the Center’s corporate outreach program turns innovative research into market-winning commercial applications. And in education, MIT is consistently ranked first among business programs in logistics and supply chain management.

For more information, please visit http://ctl.mit.edu.