Evaluating additive manufacturing as a disruptive technology in transportation & logistics

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Abstract
3D printing is exploding. With 3D printing or Additive Manufacturing, instead of products/parts being molded, cast, or machined out of blocks of metal or plastic, they are "printed" by machines that build up thin layers of plastic or metal to make an object. We evaluate AM as a Disruptive Technology.

Keywords: Additive Manufacturing, 3-D Printing, Disruptive Technology

ADDITIVE MANUFACTURING

The use of 3D printing is increasing at an increasing rate. With 3D printing (or Additive Manufacturing-AM- the two terms are used interchangeably, instead of products or parts being molded, cast, or machined out of blocks of metal or plastic, they are "printed" by machines that build up thin layers of plastic or metal, layers that can be fractions the diameter of a human hair, to make an object (Dupin 2015). Additive Manufacturing is a rapidly growing technology that threatens conventional manufacturing processes (Seally 2012). Forrest and Cao (2013) calles AM a key driver behind the paradigm shift from 20th century industrial production to the 21st century post-industrial order defined by 1) open-source collaboration; 2) intelligent nanoscale technologies; and, 3) bio technologies (Forrest and Cao 2013, 66).

While 3D printing can also be referred to as additive manufacturing, subtractive manufacturing is the opposite of additive manufacturing, and is known for being the more traditional approach to manufacturing. According to 3DPrinting.com (2015), "In the history of manufacturing, subtractive methods have often come first. The province of machining (generating exact shapes with high precision) was generally a subtractive affair, from filling and turning through milling and grinding. Additive manufacturing's earliest applications have been on the toolroom end of the manufacturing spectrum. For example, rapid prototyping was one of the earliest additive variants and its mission was to reduce lead time and cost of developing prototypes of new parts and devices, which was earlier only done with subtractive toolroom methods (typically slowly and expensively). However, as the years go by and technology continually advances, additive methods are moving ever further into the production end of manufacturing. Parts that formerly were the sole province of subtractive methods can now in some cases be made more profitably via additive ones" (What is 3D printing?, 2015).

Increasing use of Additive Manufacturing

A recent study by UPS noted that four percent of their customers were actively using the new technology, while another three times as many were experimenting with it. Of those firms using 3D printers, 75% employ it in the design process, 55% for samples, 34% for finished products, and 24% for generating spare parts. According to the 2015 Wohler's Report, viewed by many as the bible of the AM industry, business has quadrupled in the past five years to roughly $4.1 billion worldwide for all products and services directly associated with 3D printing. Research further suggests the market reached $5.2 billion in 2015 and will expand to $20.2 billion by 2019.

With this increasing growth in AM technologies and applications arises an interesting questions: 1) Is Additive Manufacturing a disruptive technology?; and 2) What are the likely future impacts on logistics and transportation? Disruptive technologies are discussed next.

What is a Disruptive Technology?

The theory of disruptive innovation was first coined by Harvard professor Clayton M. Christensen in his research on the disk-drive industry and later popularized by his book *The Innovator's Dilemma*, published in 1997. The theory explains the phenomenon by which an innovation transforms an existing market or sector by introducing simplicity, convenience, accessibility, and affordability where complication and high cost are the status quo. Initially, a disruptive innovation is formed in a niche market that may appear unattractive or inconsequential to industry incumbents, but eventually the new product or idea completely redefines the industry (Clayton Christensen Institute 2015). See Figure 1 for a two-stage process of theory building. Following this process, Christensen developed a theory of disruptive technologies. Many subsequent researchers have used his theory to describe potential disruptive technologies in manufacturing and operations management (Manyika et. Al. 2013; Walsch et. Al. 2002; Hall and Martin 2005) . Even though disruptive technologies initially underperform established ones in serving the mainstream market, they eventually displace the established technologies (Daneels 2004).

"In the process, entrant firms that supported the disruptive technology displace incumbent firms that supported the prior technology. The process is understood best by the joint consideration of the trajectories of performance offered by technological alternatives and the trajectories of performance demanded in various market segments. Initially, disruptive technologies do not satisfy the minimum requirement along the performance metric most valued by customers in the mainstream segment and thus are considered inappropriate by incumbents in the mainstream market for satisfying the needs of their customers. The products based on the disruptive technology initially only satisfy a niche market segment, which values dimensions of performance on which the disruptive technology does excel. Over time, as research and development (R&D) investments are made and the technology matures, the performance supplied by the disruptive technology improves to the point where it also can satisfy the requirements of the mainstream market. Incumbent firms, who focused R&D attention on improvements to existing technologies (i.e., sustaining technologies), have a hard time catching up with the lead of the entrants that emerged based on the disruptive technologies. Therefore, disruptive technologies tend be associated with the replacement of incumbents by entrants," (Daneels 2004, 246).

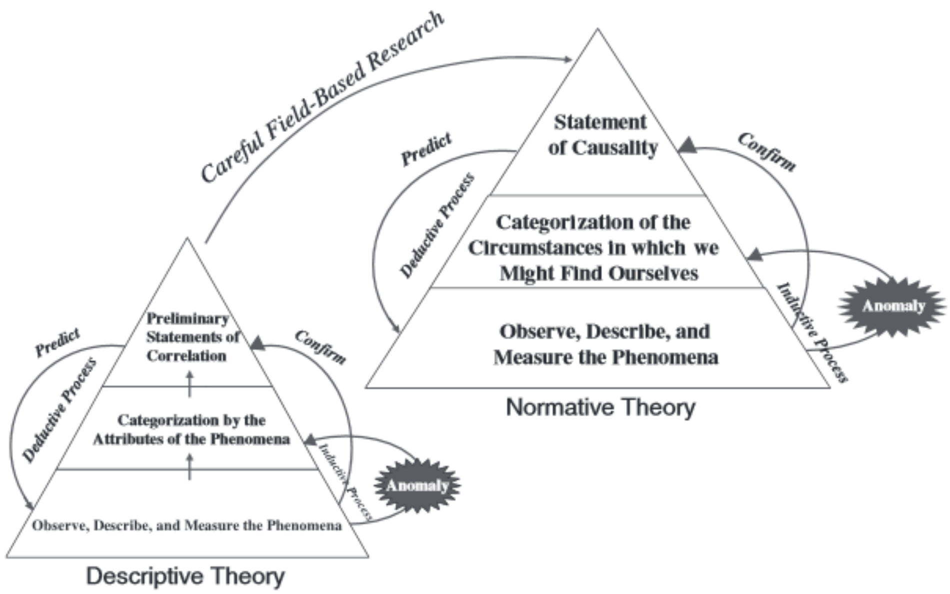

Figure 1 – Two stage process of theory building (Christensen 2006)

Sealy (2012) applied a derivative of the Theory of Constraints, termed Constraint Management, as a guide to managers in the event that AM becomes a disruptive technology. Sealy (2002) had earlier predicted that AM was evolving rapidly into a disruptive technology: "The AM industry is on the cusp of a new set of opportunities, as many of the original process patents are expiring. In the early nineties, many manufacturing experts were skeptic towards the chance of those slow and inaccurate rapid prototyping processes to be good for any other purpose than producing look-at prototypes. Today, a great deal of the challenge has been won to turn AM into a production technique with a wide scope of application that may further revolutionize the manufacturing world beyond the year 2000. As with any new and emerging technology, the need isn't always apparent. The compelling evidence from industry experts dictate AM is improving and may become a disruptive technology to conventional manufacturing processes. What this means to the users of rapid prototyping is that the future is likely to reveal not only many small, incremental changes, but also a handful of disruptive technologies that change the game entirely. Capacities and the potential of rapid prototyping technologies have attracted a wide range of industries to invest in these technologies. Although further developments need to be achieved in AM processes, the real breakthrough of AM will mainly depend on cost and productivity improvements, which have to be accompanied with further technical progress in material properties and most of all in accuracy and reliability" (Sealy, 2012, 91-92.).

Additive manufacturing has been present for over 30 years, but it hasn't been until this point that the widespread availability of technology has allowed for this to expand at the rate in which it has. "Spurred, in part, by the reduction of cost and development of direct metal technologies, we are able to visualize a disruption in the manner in which products are designed and manufactured. With the ability to efficiently manufacture custom goods, it is possible that local manufacturing could start making a return to the United States" (Campbell, et. al, 2011). The ability to manufacture anything as long as you have the computer, printer, and material needed will likely open a new realm of production that has currently been untapped in the current market. Additive manufacturing will see a drastic rise to power as it is able to drastically reduce costs associated with traditional manufacturing methods. AM allows for the reduction in costs associated with overseas transportation, distribution, packaging, and production facets of operation.

Dissemination of Additive Manufacturing

The dissemination of 3D printers is increasing rapidly. One of the main reasons for this is the new affordability of the printers. They have the ability to reduce assembly lines, reduce supply chains, and can produce a product in one additive continuous process (as opposed to making separate, numerous parts). Desktop 3D printers can now be purchased for a price of $1,000 (Campbell et al, 2011). This much more affordable price tag has opened the door for the average consumer and hobbyist. Before, only large design firms and manufacturing firms were using the technology because of the price tag associated with additive manufacturing. However, with the new affordability, additive manufacturing now resembles the early stages of the Apple I's impact on personal computing (Campbell et al, 2011).

As additive manufacturing disseminates, more opportunities open up to the limitless possibilities of additive manufacturing. One such improvement that is helping spread the effectiveness of additive manufacturing is through the improvements in functionality of metal components. "Significant improvements in the direct additive manufacture of metal components have been made in the past five years. Engineers are now able to fabricate fully-functional components from titanium and various steel alloys featuring material properties that are equivalent to their traditionally manufactured counterparts. As these technologies continue to improve, we will witness greater industrial adoption" (Campbell et al, 2011). By improving the practicality of additive manufacturing, the dissemination of additive manufacturing is inevitable. Campbell (2011) paths of growth. The first path or the high end path, involves expensive high-powered energy sources and complex scanning algorithms (Campbell et al, 2011). This path focuses on developing the proper technology to become more aligned with industry standards and gaining acceptance for industry applications. The other path is considered the low end path because it focuses on reducing the complexity and cost of additive manufacturing so that it may be more readily available to the public. As these two separate paths continue to move forward, we can expect to see them come together to meet in the middle to create the additive manufacturing of the future. As Campbell stated, "These systems will also see broader dissemination in the next 5 years—first through school classrooms and then into homes.

While these two technical paths 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, in the next few decades" (Campbell et al, 2011). As time continues to move forward, the increase in dissemination of additive manufacturing will continue to grow.

Impact on Logistics and Transportation

Disruptive technologies create growth in the industries they penetrate or create entirely new industries through the introduction of products and services that are dramatically cheaper, better, and more convenient (Kostoff et. al., 2004). Increasingly it I apparent that AM is indeed a disruptive technology. In the near future, it is not unreasonable to see a firm send an electronic code to a remote site to print a replacement part, thus eliminating the cost and time and associated externalities (e.g. carbon footprint) of shipping a product with traditional transportation modes (e.g., truck, air carrier, maritime carrier, railroad). Logistically, the process will enable fewer inventories, warehouses, and the inventory carrying costs of provision. The 3D printing revolution (and rapid dissemination) may reshape traditional supply chains.

Transport companies will likely find ways to use AM to support their own operations (Dupin 2015). The use of 3D printers will likely lead to the manufacture of products closer to their point of consumption, reducing or eliminating the need to transport products distantly. The Dutch carrier Maersk has investigated the use of AM in a preventative, cost saving. For instance, Maersk has investigated making spare parts for a tanker or an oil rig. When apart is needed a signal can be sent to the on-board vessel and it can be operating again in a matter of hours. Currently, the opportunity cost of waiting for a delivery of a part is exceedingly costly. The logistics of delivery at sea is also extremely complex. Dupin (2015) notes that the opportunity cost of a shut down oil rig at sea exceeds $511,000 daily.

Many other logistics firm are responding to this changing paradigm due to AM. For instance, UPS has installed 3D printers at may of its U.S. locations in anticipation of the new market demands. New cloud-based additive manufacturing firms are also locating near the hubs of hub and spoke networks like UPS' Louisville, KY, location and FedEx' Ohio River Valley airports.

The market continues to see AM becoming more capable and efficient. Quality issues from their genesis are rapidly being answered and mitigated. Materials are becoming more standardized and we see increasing use of polymers and metals, rather than simply plastic. Will this disruption make a drastic impact on traditional subtractive manufacturers? Many in the transportation and logistics and supply chains sectors think so and are preparing accordingly. It seems that AM is likely to be a disruptive technology in certain sector of manufacturing sooner than in others. Nonetheless, some firms are positioning themselves to capitalize on this disruptive technology now.

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