OFFICE OF INSPECTOR GENERAL
UNITED STATES POSTAL SERVICE

If It Prints, It Ships:

3D Printing and the Postal Service

RARC Report

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OFFICE OF INSPECTOR GENERAL
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Executive Summary

As 3D printing spreads and moves production closer to consumption, it could have major implications for everyone along existing supply chains, including the U.S. Postal Service.

We are living in a world where it is possible to convert digital files at one location into physical objects at another, transforming bits into atoms. We can do this with 3D printing, a technology that turns customers into creators and has the potential to make a significant impact on the $10.5 trillion global manufacturing industry. 3D printers build solid objects usually one razor-thin layer at a time using plastics, powders, metals, polymers, or other materials. New techniques are rapidly expanding the capabilities of this technology, such as producing surfaces as smooth as glass. People are already using 3D printing to create a wide range of things, from airplane parts, dental implants, and custom-fit hearings aids to personalized iPhone cases and tiny action figures. In addition, scientists are experimenting with using 3D printing to replicate and replace living human tissues, producing a “bioink” that could someday revolutionize medical care.

As 3D printing spreads and moves production closer to consumption, it could have major implications for everyone along existing supply chains, including the U.S. Postal Service. 3D printing could lead to more single-item parcels being shipped to consumers over shorter distances, instead of hundreds of thousands of identical items sent by containerized cargo over vast distances. It could also lead to reduced fuel consumption and exhaust emissions, as well as less material waste due to precise manufacturing. Moreover, 3D printing could make large retailers rethink their need for maintaining expensive and duplicative warehouses stocked with massive inventories in favor of just-in-time inventory.

The size of the 3D printing industry helps to convey how important it could be to the American public and the Postal Service. The total 3D printing industry was valued at around $3 billion in 2013 and is expected to grow to $16.2 billion by 2018. Given its potential size, 3D printing could start to reshore previously outsourced manufacturing back to the United States. Someday very soon, 3D printing could be a powerful engine for job creation and economic growth.

3D printing has already come to dominate rapid prototyping and is fundamentally altering other industrial activities. However, much of the excitement around 3D printing is driven by the

Highlights

3D printing is in the initial stages of transforming major parts of our economy, such as aerospace and healthcare. It also promises to revolutionize the way consumers get customized goods by making them cheaper and more accessible.

Prominent industry forecasts show the 3D printing market exploding over the next several years.

3D printing could lead to an increase in packages delivered by the Postal Service worth $485 million in new annual revenue, based on analysis of commercial package volume data.

Emerging 3D printing businesses could use the ubiquitous first- and last-mile postal network to connect with their customers.

The Postal Service could partner with 3D printing businesses, perhaps using excess space in postal facilities, to help streamline the fast delivery of 3D printed goods.

potential for customized products. 3D printing allows people to actually design or buy things that previously existed only in their imagination. This wave of mass customization is converging with an emerging maker movement — innovative artisans, entrepreneurs, and everyday people who can use 3D printing to bring their digital creations into the physical world. 3D printing has the power to democratize manufacturing by giving more people access to production and allowing them to make unique items. As the list of things that can be printed continues to grow, consumer interest in 3D printing will gain momentum.

The Postal Service could benefit tremendously by the rise of 3D printing. This is primarily due to two factors: the Postal Service's ubiquitous first- and last-mile delivery network and its strength in handling lightweight goods. The Office of Inspector General asked Christensen Associates — a renowned economic consulting firm with extensive knowledge of Postal Service operations — to assess how 3D printing could affect the Postal Service. By analyzing commercial package data, Christensen Associates estimated that 3D printing could raise the Postal Service's annual package revenue by $485 million as businesses ship increasing numbers of 3D printed goods to consumers.

To capture the potential benefit of 3D printing, the Postal Service must at least maintain its current delivery network and keep pace with evolving consumer needs. Many 3D printed products will be manufactured closer to where consumers live but will still need last-mile delivery. Businesses wishing to put their 3D printed products in the hands of consumers as quickly and conveniently as possible may need the ubiquitous postal network. And if people someday print many items directly, they may frequently need 3D printing supplies such as powders and binding materials delivered. No other organization covers as much ground as frequently and reliably as the Postal Service. Moreover, the generally small and lightweight nature of 3D printed items makes them a perfect fit for delivery by the Postal Service. Private delivery firms already use the Postal Service for final delivery of many of their own small packages because the Postal Service's network allows it to deliver these packages more cost effectively.

The Postal Service could take further actions to ensure that it helps to meet the future needs of citizens and businesses. For example, the Postal Service could partner with 3D printing companies and even potentially bring some printing onsite at postal facilities, as well as provide microwarehousing to help ensure rapid shipment of 3D printed goods. The Postal Service could also help protect copyrighted or sensitive digital design files by providing a trusted online marketplace for transmission of designs, or by delivering some files physically through carriers. This could bring a level of security, confidentiality, and privacy that the Internet cannot match. In addition, the Postal Service could look into how advertisers might use 3D printing to customize offerings and better connect with consumers. The Postal Service could also use 3D printing to improve its own internal operations by printing spare parts to repair vehicles and mail processing equipment more efficiently.

The 3D printing revolution has only just begun. 3D printing has the potential to be amazingly disruptive, and some people think the changes brought on by it will exceed even those of the Internet. While the Internet did much to overcome the challenges of time and distance by making everything local, 3D printing could take things to the next level by making on-demand products at any location. The question is, who will win from a 3D printing revolution and who will lose? By embracing this groundbreaking technology, the Postal Service could put a compelling 21st century twist on its historical mission to serve citizens and facilitate commerce.

Table of Contents

Table of Contents

Observations

3D printing could be the biggest change to global manufacturing since the invention of assembly lines.

Every 3D printed item ordered could be another package that needs home delivery.

Introduction

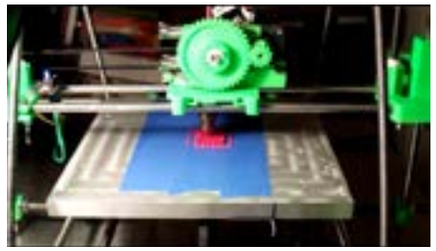
Few of today's emerging technologies have attracted as much attention as 3D printing. Many argue that it could change vast swaths of the global manufacturing sector, much in the way the Internet revolutionized communication.[1] This technology allows people to create physical objects out of digital designs — often building them one razor-thin layer at a time — and has the potential to democratize the means of production. Theoretically, anyone with a 3D printer can make virtually any object they can imagine and design, subject to some basic limitations. If, as some predict, people 3D print many of the things they need on their own instead of buying them online or at brick-and-mortar stores, global supply chains could shatter, longstanding industries could collapse, and many aspects of life as we know it could change.

Since the 1990s, 3D printing has driven big changes in some industries, unseen by many consumers. Given the tremendous scale of global manufacturing, even a tiny disruption could have far-reaching consequences. Because the consumer 3D printing revolution is still in its early stages, it is not yet clear exactly who will win from this significant disruption and who will lose. While this technology promises to have profound ramifications for businesses all along the supply chain — including the U.S. Postal Service — some of the fervor is based on unrealistic hype. This paper attempts to sift through much of that hype and get at the technology's real possibilities and implications.

Despite the hype and some uncertainty about the exact magnitude of the market, it is clear that 3D printing will be a substantial force. It has been hailed as the next industrial revolution and "the biggest single disruptive phenomenon to impact global industry since assembly lines."[2] A recent analysis forecasts the 3D printing industry growing to $16.2 billion by 2018.[3] McKinsey estimates that 3D printing's total economic impact could be as large as $550 billion per year by 2025.[4] If 3D printing took over just 2 percent of the $10.5 trillion global manufacturing industry, it would be a $210 billion annual industry.[5] Moreover, a sweeping 3D printing revolution could radically change how some industries function, potentially transforming the notion of warehousing, removing some of the need for long-haul shipments, and bringing more manufacturing jobs back to the United States. In such a world, consumers might come to demand the customization enabled by 3D printing that they cannot get from today's mass production techniques. By helping this emerging class of manufacturers to thrive, the Postal Service could enhance the economic potential of this technology.

In addition, the rise of a vibrant, nationwide "maker" movement of people experimenting with 3D printing reflects the strong interest small-scale entrepreneurs and artisans have in this technology. Individuals are already using 3D printing for all sorts of everyday items like jewelry and pencil holders, while industrial printers are producing things like car parts, clothing, and musical instruments. On a larger scale, 3D printing is fueling major advances in medicine and industrial engineering.

Video 1: 3D Printing Video



Source: PBS Off Book, via YouTube http://youtu.be/X5AZzOw7FwA.

Imagine a world where customers can easily modify countless products to their exact specifications, and order these unique items via the Internet for home delivery. Every product ordered could be another product that needs shipping, which could lead to big increases in package deliveries for the Postal Service. However, the widespread use of 3D printers in American households could divert some of the lightweight packages now handled by the Postal Service. Fortunately, if people print many items at home, they would need a constant supply of printing materials, many of which would need delivery.

In addition to examining the facts, trends, and implications of 3D printing for the Postal Service, this paper also proposes several potential strategies the Postal Service could follow to best position itself for the future.[6]

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1 Wohlers Associates, *Wohlers Report 2013: Additive Manufacturing and 3D Printing State of the Industry, Annual Worldwide Progress Report,* p. 128.

2 Transport Intelligence, T*he Implications of 3D Printing for the Global Logistics Industry,* August 2012, http://www.transportintelligence.com/forms/get_whitepaper.php?wpID=76, p. 1.

3 Canalys, *3D Printing Market to Grow to U.S. $16 Billion in 2018,* March 31, 2014, http://www.canalys.com/newsroom/3d-printing-market-grow-us162-billion-2018. The industry was worth $3 billion in 2013. Please see Wohlers Associates, "Wohlers Report 2014 Uncovers Annual Growth of 34.9% for 3D Printing and Additive Manufacturing Industry," news release, May 1, 2014, http://wohlersassociates.com/press63.html.

4 McKinsey Global Institute, *Disruptive Technologies: Advances That Will Transform Life, Business, and the Global Economy,* May 2013, http://www.mckinsey.com/insights/business_technology/disruptive_technologies, pp. 105, 110.

5 "3D Printing Industry Predictions from Terry Wohlers," *3D Innovations*, http://www.3d-innovations.com/blog/3d-printing-industry-predictions-from-terry-wohlers/.

6 For this project, we hired Laurits R. Christensen Associates, an economic consulting firm with in-depth knowledge of U.S. Postal Service operations.

Rapid prototyping is the most common use of 3D printing today because it enables quicker, cheaper, and more adaptable designs.

What is 3D Printing?

At a very basic level, 3D printing is the production of physical objects from virtual representations — like printing a coffee mug from a digital design of a mug. Although 3D printing sounds like something straight out of a science fiction novel, the technology has existed in various forms for decades.[7] People used most early 3D printers for research, scientific purposes, and a few industrial processes. Only recently has 3D printing emerged as a commercially viable method for producing consumer goods, due to advancements in technology and materials, as well as more industry acceptance of 3D printing's value.

There are several different techniques used for 3D printing. The most common uses materials pushed out of a heated nozzle — similar to a hot glue gun — to build objects layer by layer. Other techniques use lasers to create solid objects out of liquid resin or dry powder that is selectively melted, or use glue to fuse together sheets of plastic or paper that are cut to specific shapes. Regardless of the technique, 3D printing is categorized as a type of "additive manufacturing," meaning that it adds materials together to create a new object. This is the opposite of subtractive manufacturing, where material is cut away from solid objects to create a final product.

Figure 1: 3D Printed Dental Implant

Source: 3D Systems.

The digital images that turn into 3D printed objects come from a few different sources. Computer-aided design (CAD) programs can create virtual representations of physical objects or items that are purely imaginary. Users can also access digital files from various websites with pre-existing designs, and then use those files to print the objects directly or modify them before printing. In addition, 3D scanners capture physical objects and convert them into digital files that can then be used by a 3D printer to reproduce the physical object. There are even apps that can turn a smartphone or tablet into a 3D scanner.[8]

What Are People 3D Printing?

Most people are familiar with some of the knick-knacks and unusual items 3D printers are cranking out right now. Countless news articles have covered 3D printed smartphone cases, key chains, custom chess pieces with your face on them, and other such products. The news media has paid less attention to the numerous practical uses for 3D printing. For example, Align Technology uses 3D printing to create each one of its popular Invisalign custom-fit, transparent braces.[9] Since 1997, the company has manufactured nearly 150 million aligners.[10] 3D printing can also create custom-made hearing aids, prosthetic limbs, and other crucial medical devices. Given how quickly 3D printing has changed some industries already, other industries could change rapidly.

Rapid prototyping is the current primary driver of 3D printing. It allows for comparatively quick and simple production of first-of-its-kind goods and gives engineers a greater ability to make swift changes in prototype design. Companies can even crowdsource consumer preferences and product improvements through 3D printing by releasing designs for several different versions of a product and collecting feedback on which version is most appealing.[11]

The aerospace and automotive industries also have shown that 3D printing can drive new efficiencies. F-18 fighter jets, which have been in service for more than two decades, have about 90 parts per plane made with 3D printing.[12] Airbus is already saving millions of dollars per year by replacing parts on each plane with 3D printed components. The minor drop in weight per aircraft —

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7 Terry Wohlers and Tim Gornet, *Wohlers Report 2013: History of Additive Manufacturing*, p. 15.

8 For examples of 3D scanning technology, please see http://www.3ders.org/3d-scanning.html.

9 Martha Mendoza, "3-D Printing Goes From Sci-Fi Fantasy to Reality," *Associated Press*, June 2, 2013, http://bigstory.ap.org/article/3-d-printing-goes-sci-fi-fantasy-reality, and "Treatment Process," *Invisalign*, http://www.invisalign.com/how-invisalign-works/treatment-process.

10 Align Technology, *Corporate Fact Sheet: Q1 2014*, http://www.aligntech.com/documents/Align%20Technology%20Corp%20Fact%20Sheet%202014%20Q1_F.pdf.

11 Daniel Cohen, Matthew Sargeant, and Ken Somers, "3-D Printing Takes Shape," *McKinsey Quarterly,* January 2014, http://www.mckinsey.com/insights/manufacturing/3-d_printing_takes_shape.

12 "3D Printing Scales Up," *The Economist*, September 5, 2013, http://www.economist.com/news/technology-quarterly/21584447-digital-manufacturing-there-lot-hype-around-3d-printing-it-fast.

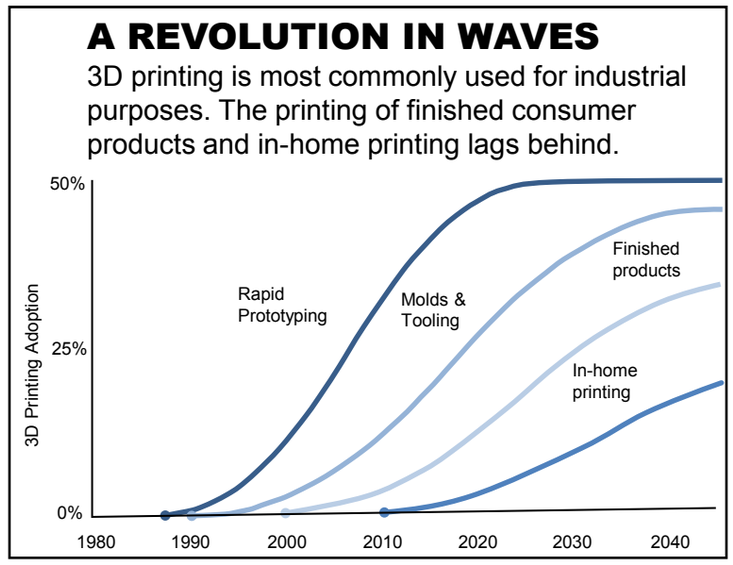
3D printing is already fundamentally changing the aerospace, medical, dental, automotive, entertainment, and other industries.

as little as 2.5 kilograms — multiplied across tens of thousands of flights results in big savings.[13] In addition, Kelly Manufacturing Co. is 3D printing components for critical aircraft flight instruments. With 3D printing, the turnaround time on these low-volume parts has improved and the cost-per-part has decreased.[14] In the automotive industry, BMW is using 3D printing to build light, ergonomic tools for workers on their assembly lines. 3D printing can create parts that are mostly hollow, which makes their continued use over an entire workday far less strenuous for the assembly line workers.[15]

In addition to industrial and commercial uses of 3D printing, there is also an active community of 3D printing hobbyists. Beginning in 2009 or so, the expiration of key patents, combined with significant decreases in costs of critical components, enabled a grassroots, open-source 3D printing community, which makes its designs and knowledge base freely available online.[16] Objects produced by hobbyists may be educational, artistic, or fun. Some are even functional, such as footwear, chip clips, and bottle openers. A flourishing maker movement in the United States has fueled interest in 3D printing as a means for innovative and more accessible design and production.

Figure 2 depicts four major uses of 3D printing and rough adoption projections for each. Rapid prototyping led the first wave because of the flexible design capabilities of 3D printing. The second wave involves improvements to traditional manufacturing techniques through targeted use of 3D printing. These first two are generally industrial applications, and will likely have limited impact on the Postal Service. The third key use is the 3D printing of finished goods or parts directly for consumer use. In-home 3D printing is the most recent trend and the one whose path is most uncertain.[17] These final two applications are likely to have a strong impact on the Postal Service, as discussed later in this paper. For more examples of how people are using 3D printing, please see Appendix A.

Figure 2: Areas of Application for 3D Printing



Source: Rough projections by Christopher Barnatt, ExplainingTheFuture.com.

Strengths and Weaknesses of 3D Printing

3D printing has numerous important advantages over traditional manufacturing techniques. It is ideal for creating objects that are relatively small and customized to individual consumers or applications.[18] 3D printing allows for short, specialized production runs that do not require extensive reconfiguration of machines as in traditional manufacturing. The process is highly automated, in theory allowing people with little to no machine shop experience to produce highly specialized physical objects. 3D printing is also well suited to items with expensive materials because it can minimize waste and produce items with up to 75 percent less material.[19] Finally, 3D printing can produce objects with more complex designs than would be practical or even possible with traditional manufacturing techniques.

However, 3D printing currently has some important limitations. For example, the range of materials available for printing is limited, which reduces the number of things that can be printed. The 3D printing process itself can lead to weak spots in finished products, given its layer-by-layer construction and potential flaws in some 3D designs. In addition, the simpler 3D printers are limited to using only single materials for each object printed. Importantly, 3D printing takes a long time for larger objects as modest increases in size can require dramatically longer times to print. Moreover, the technology is still evolving and some existing printers are

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13 Curtis Carson, Head of Systems Integration, Centre of Competence Manufacturing Engineering at Airbus, quoted in "Airbus Envisions a 3D Printed Future," *On 3D Printing*, April 4, 2014, http://on3dprinting.com/2014/04/04/airbus-describes-3d-printed-future/.

14 Stratasys, *Kelly Manufacturing Case Study*, http://www.stratasys.com/resources/case-studies/aerospace/kelly-manufacturing.

15 Stratasys, *BMW Case Study*, http://www.stratasys.com/resources/case-studies/automotive/bmw.

16 McKinsey Global Institute, *Disruptive Technologies*, p. 108.

17 Christopher Barnatt, "3D Printing: The Business Opportunities," *3D Printer*, October 7, 2013, http://www.3dprinter.net/3d-printing-the-business-opportunities.

18 Zack Schildhorn, "The Big Picture on 3D Printing: A VC Perspective" (presentation at Inside 3D Printing Conference + Expo, New York, Thursday, April 3, 2014).

19 For examples, please see http://www.naefrontiers.org/File.aspx?id=39131, http://www.usrepresented.com/2013/12/19/additive-manufacturing/, and http://www.3ders.org/articles/20131024-3d-printing-can-cut-material-consumption-co2-emissions.html.

Table 1: Comparison Between 3D Printing and Traditional Manufacturing

3D PRINTING VS TRADITIONAL MANUFACTURING

Traditional manufacturing processes often require expensive, custom-configured equipment designed to mass produce products. 3D printers, conversely, make unique items from digital designs, often building them layer by razor-thin layer. Here is how the processes stack up.

	3D Printing	Traditional Manufacturing
Speed	Once you have the design file, there is little upfront time required to begin printing, though each item can take a long time to print. This makes it ideal for prototyping, small production runs, or customized products.	It takes a great deal of time and resources to set up machines for production. However, once fabrication begins, each item can be manufactured quickly. This makes it ideal for mass production of identical items.
Cost	There are low upfront costs, but often relatively high per-unit costs. There is minimal need for skilled labor (other than design).	There are high upfront costs, but relatively low per-unit costs. It also requires skilled workers to configure and operate machines.
Flexibility	Complex or hollow items are no more difficult to print than simple items. Also, designs can be adjusted or customized easily, allowing manufacturers to respond quickly to customer preferences. However, the relatively young technology still has a limited array of materials that can be used, and it is not well suited for making some types of products.	Retooling costs make it impractical to customize or experiment with new product designs. Also, it is often impossible to make certain designs in a single piece, including hollow or highly intricate items. However, techniques already exist to produce a virtually limitless array of items using a broad swath of materials.

Source: U.S. Postal Service Office of Inspector General (USPS OIG) analysis.

prone to breakdown and minor errors in production, resulting in objects that are useless.[20] It also can take precisely controlled environmental conditions to get a high-quality print due to the sensitivity to temperature, wind, and humidity in melting processes. Finally, the characteristics that make a material a good candidate for 3D printing, such as a low melting point, also can make the resulting parts unsuitable for durable use without significant post-production processing. For example, a dashboard GPS mount printed with plastic can become soft or melt down entirely in a vehicle left in the hot sun.

Table 1 highlights some of the key differences between 3D printing and traditional manufacturing.

Because of these advantages and limitations, 3D printing is generally best suited for relatively small production runs. Once the number of units produced is large enough, traditional manufacturing methods are usually more cost-efficient. Figure 3 shows conceptual cost curves for traditional manufacturing and 3D printing. The area to the left of the intersection of the lines represents production runs that are ideal for 3D printing because it would cost less to produce that quantity of items with 3D printing than traditional manufacturing. It is important to note that the cost curve for 3D printing will move downward as technological advancements make the process easier, faster, and cheaper. As the costs decrease, the area to the left of the intersection grows larger — representing an increased number of goods well suited for 3D printing. For non-identical items, 3D printing is already likely the most efficient process in many cases.

The Precise Future of 3D Printing is Still Uncertain

Given the disruptive potential of 3D printing and the pace at which the market is changing, nobody knows exactly how 3D printing will evolve. Some experts say the technology will completely revolutionize the way we create and consume nearly everything, and that 3D printers will one day be as common in households as microwave ovens. Others say 3D printing will just gradually change how a number of key industries work, remain a niche technology used mostly by dedicated hobbyists, or continue as a tool best meant for rapid prototyping and other industrial uses. Regardless of precisely how it evolves, 3D printing is likely to move production closer to the point of consumption and could call into question longstanding tenets of manufacturing, including the need for centralized factories, rigid supply chains, and commoditized mass production.[21]

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[20] For examples of failed 3D prints, please see http://epic3dprintingfail.tumblr.com/.

[21] Institute for the Future, *The Future of Open Fabrication*, http://www.iftf.org/uploads/media/SR-1390_FutureOfOpenFab.FINAL_sm.pdf, p. 8.

The more objects people want to print, the more they will want access to 3D printing. This will be the primary market driver, rather than advancements in technology alone.

Growth of the 3D Printing Market

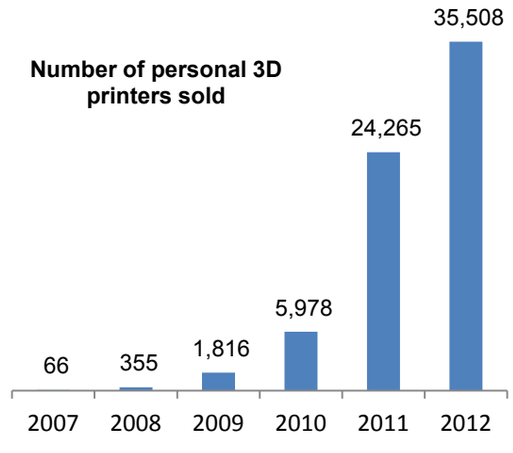
Like many modern technologies, 3D printing is changing rapidly. Shifts in consumer preferences, technological advancements, and other factors are drastically altering how and why businesses and consumers use 3D printing. The global market for 3D printing, consisting of all products and services, had a compound annual growth rate of 34.9 percent in 2013 — the highest in 17 years.[22] This could be solid evidence that the 3D printing revolution has begun. Sales of industrial printers, generally considered those that cost more than $5,000, have increased over the past couple of decades, with an average compound annual growth rate of 31.1 percent from 1989 to 2012.[23]

In addition, sales of personal or desktop 3D printers — those that cost $5,000 or less — have skyrocketed in the past few years. Figure 4 shows the estimated number of personal or desktop 3D printers sold between 2007 and 2012, when there was a substantial leap in the number of printers sold — even if these devices represent only a small portion of the overall 3D printing market. The size of the personal 3D printer market is difficult to measure because such estimates generally do not count 3D printing hobbyists who sometimes build their own machines. As a result, the actual number of personal 3D printers inside homes and small businesses is likely much higher. There also are recent examples of personal 3D printers that attract a great deal of attention from the public. One Kickstarter campaign for a consumer 3D printer sold more than 9,000 units in 10 days, and raised more than $2 million in just 3 days.[24] The campaign had an original crowdfunding goal of raising just $50,000 in 30 days — a goal that it met in just 11 minutes.[25]

Figure 4: Sales of Personal 3D Printers

PERSONAL PRINTERS TAKING OFF

Sales of personal 3D printers have surged in recent years, with the average machine selling for $1,124 in 2012 — just a fraction of the nearly $80,000 price tag fetched by the average industrial machine.

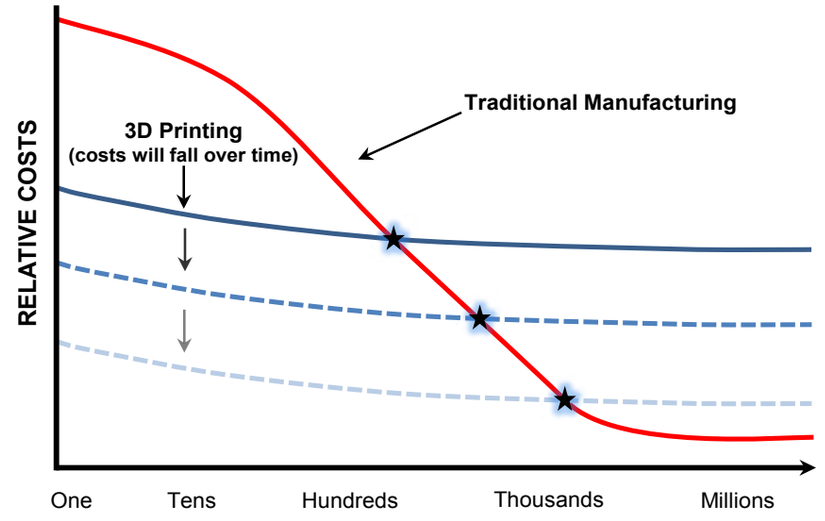


Source: Wohlers Report 2013.

Figure 3: Cost Comparison Between 3D Printing and Traditional Manufacturing

THE ECONOMICS OF 3D PRINTING VS MASS MANUFACTURING ARE CHANGING

3D printing of identical finished products only makes economic sense if you're printing a limited number. For larger quantities, traditional manufacturing currently costs less per unit. But as 3D printing gets faster and cheaper (shown with the dotted lines below), the unit threshold where it makes economic sense to 3D print items will increase. As that happens, a cascade of industries may switch to 3D printing to save on manufacturing costs.



Source: Zack Schildhorn, Lux Capital. Modified by the USPS OIG. These conceptual cost curves are purely illustrative.

Ultimately, the number of applications of 3D printing, and not merely the technology itself, will likely drive its popularity in the consumer market. In other words, as the universe of "things to print" gets larger, consumer demand is likely to grow. Having robust and accessible sources of virtual objects will therefore boost the overall growth of 3D printing. The largest current library of virtual objects is MakerBot's Thingiverse.com,

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22 Wohlers Associates, "Wohlers Report 2014 Uncovers Annual Growth of 34.9% for 3D Printing and Additive Manufacturing Industry," http://wohlersassociates.com/press63.html.

23 Wohlers Associates, *Wohlers Report 2013: Additive Manufacturing and 3D Printing State of the Industry, Annual Worldwide Progress Report*, pp. 129-130.

24 Kickstarter is a website that allows people to solicit small dollar investors to fund a project, https://www.kickstarter.com/projects/m3d/the-micro-the-first-truly-consumer-3d-printer.

25 Salvador Rodriguez, "Micro 3-D printer reaches Kickstarter goal of $50,000 in 11 minutes," *Los Angeles Times*, April 7, 2014, http://www.latimes.com/business/technology/la-fi-tn-micro-3d-printer-kickstarter-50000-11-minutes-20140407,0,7778172.story#axzz30ZN0CDwc.

Where will consumers get the 3D printed products they need — from printers inside their homes or from businesses selling finished 3D printed goods? Perhaps both at the same time, depending on what they need.

The Postal Service has the most to gain from 3D printing compared to other delivery firms.

which contains more than 100,000 design uploads from users.[26] Also, the existing trend toward mass customization will likely grow and intensify. In fact, this desire for customized goods may be the most significant factor in the growth of 3D printing.[27]

Regardless, the cost of printers and the range of available printing materials will always be important factors. Overall, 3D printers are getting cheaper. Just a few years ago, they were enormously expensive and outside many people's price range. Today, low-end, hobbyist machines now can cost less than $300. In addition, printing materials are no longer limited to just basic plastics or metals. There are now filaments made from nylon that can be used to create flexible parts, as well as filaments partially made from wood that can be drilled or cut similar to natural wood. As printers and printing materials become more capable, useful, and available, the public's uptake of 3D printing is likely to increase. Improvements in the software used to design virtual objects also will help fuel the growth of 3D printing.

Intellectual Property and Liability Issues

Lingering questions about intellectual property, patent protection, and liability also will shape this technology's future. In a world with ubiquitous 3D printers or 3D printing services, discovering and combating the infringement of intellectual property rights and patents is likely to become increasingly difficult, if not impossible. Once the public has access to a digital design file, widespread reproduction of the object becomes a real possibility — whether or not the creator or rights holder for the design wants it. In many ways, this is similar to what happened to digital music once files appeared on online filesharing sites. In addition, as 3D printing becomes more popular there may be increasing concerns about liability issues. For example, if a 3D printed part fails, who is the responsible party — the person who printed the object, the creator of the digital design, the manufacturer of the printer itself, the raw materials supplier, or someone else entirely? These issues will likely play out in the courts over the coming years and decades.

Where Will Consumers Access 3D Printing?

Many big questions hang over the future of 3D printing. Will mass customization replace a significant share of mass production? And, if so, where will consumers go to access 3D printing? Will they buy the 3D printed products and services they need from businesses and have them delivered? Will they print what they need at home? Will they do both? Will they even know what products are being fully or partially 3D printed? Manufacturers with high-end printers can make products or parts for others on demand, offering a nearly limitless assortment of customized goods while keeping physical warehousing needs to an absolute minimum. Because consumers can get their 3D printing needs fulfilled quickly, cheaply, and easily by such businesses, many consumers will likely use in-home 3D printers for much more limited purposes.

The advance of "2D" ink printers might help shed some light on how this could play out. To be clear, there are fundamental differences between 2D and 3D printing, and people's relationship with two-dimensional information is different from their relationship with three-dimensional objects. Nevertheless, the analogy is useful. Throughout most of their history, 2D printers were large, labor-intensive industrial machines that had to be hand-configured for each item they were printing. Much like traditional factories today, they were best at doing large runs of identical items. However, digital printing advances that began in the 1970s changed things dramatically. Within a few decades, inexpensive desktop machines that could print high quality, color images would become ubiquitous. However, those in-home printers did not replace the need for professionally printed materials. It did not make sense for people to print their newspapers, magazines, and books at home. Such mass-produced products are still printed on big industrial machines. Even for smaller-run items like brochures, invitations, or posters, most people prefer to print them at local copy centers, which have equipment with the speed and capacity to produce high-quality items more quickly.

These same dynamics may hold true for 3D printing. Some theorize that every home will have a 3D printer one day, which people will use to make all sorts of items that they currently buy at retail stores or online. A Michigan Technological University study even asserts that 3D printers are already cost-effective home appliances.[28] While people may be able to use their in-home printers for some items, based on this 2D printing analogy, it is likely that most products will still be manufactured by traditional means or industrial grade 3D printers. It is also likely that local 3D printing centers, similar to existing copy centers, could serve as a place

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26 "About," *MakerBot Thingiverse*, http://www.thingiverse.com/about.

27 Paul Willis, "New Dimension," *Postal Technology International*, March 2013, http://www.postaltechnologyinternational.com/articles.php?ArticleID=552.

28 B.T. Wittbrodt, A.G.Glover, J. Laureto, G.C. Anzalone, D. Oppliger, J.L. Irwin, and J.M. Pearce, "Life-Cycle Economic Analysis of Distributed Manufacturing with Open-Source 3-D Printers," *Mechatronics*, 6, No. 23 (September 2013), http://www.sciencedirect.com/science/article/pii/S0957415813001153, pp. 713-726.

where people could both scan items they would like to recreate or order professional-grade 3D prints of designs they may have purchased online.

3D Printing Could Bring Substantial Benefits and Opportunities for the Postal Service

Most 3D printed items are lightweight, and the Postal Service delivers nearly two-thirds of all lightweight commercial packages.

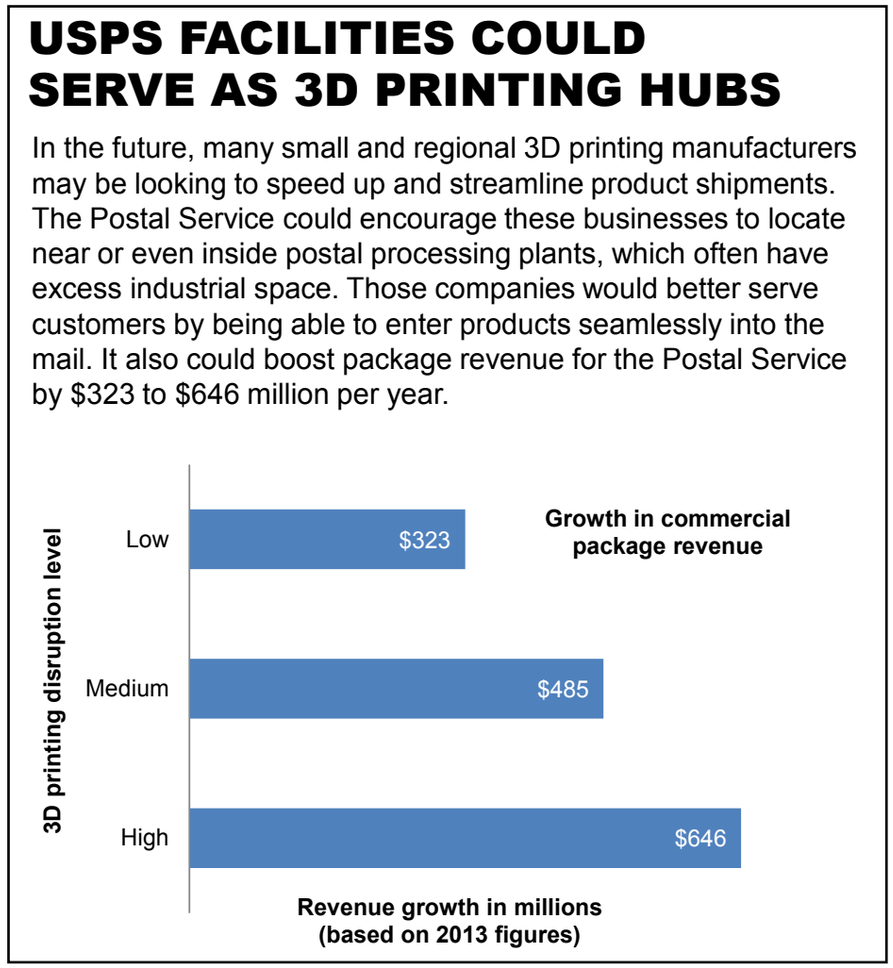
A 3D printing revolution might be a huge opportunity for the Postal Service. This is primarily due to two factors: the Postal Service's ubiquitous delivery network and its strength in handling lightweight goods. The Postal Service has an unmatched last-mile delivery network. Six days per week, it delivers to 153 million addresses across the United States. In addition, it has more than 211,000 vehicles that drive about 1.2 billion miles annually.[29] Moreover, it employs nearly 114,000 rural carriers and nearly 198,000 city carriers who not only deliver letters and packages, but also can pick up items to be shipped.[30] No other organization covers so much territory as frequently and reliably.

The Postal Service also has a natural advantage in delivering lightweight goods, given its ubiquitous presence and frequency of delivery. It is often not cost effective for private delivery firms to make separate stops to deliver small, relatively inexpensive packages — particularly in rural areas. However, the Postal Service is already visiting these locations every day. As such, other delivery firms often use the Postal Service for last-mile delivery.[31] In fact, nearly two thirds of lightweight, commercial packages are delivered to their final destination by the Postal Service.[32] This is directly relevant to 3D printing, as the vast majority of 3D printed consumer goods are relatively lightweight.33 There are several reasons for this. First, most 3D printing materials themselves are lightweight. Second, many 3D printers have relatively small print areas. Third, designers intentionally create many 3D printed objects to be lightweight with holes or other cutout areas that reduce excess materials and therefore weight. Finally, because it takes significantly more time to produce larger and heavier goods, these bulkier items are far more often produced by conventional methods.

Emerging 3D printing businesses could use the ubiquitous first- and last-mile postal network to connect with their customers.

We asked Christensen Associates to assess what impact a 3D printing revolution could have on the Postal Service. To do so, Christensen Associates analyzed commercial package data from fiscal year 2013 (October 1, 2012 to September 30, 2013), focusing on industries and parts of the supply chain that would likely be affected by increased levels of 3D printing. For example, 3D printing is likely to affect the market for toys, electronics, jewelry, and auto parts. Christensen Associates conducted a

Figure 5: Postal Facilities as 3D Printing Hubs



Note: Above revenue increases do not take into acocunt potential leasing income.
Source: USPS OIG graphic based on data from Christensen Associates.

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29 U.S. Postal Service, "About Us," http://about.usps.com/who-we-are/postal-facts/size-scope.htm.

30 U.S. Postal Service, "Postal Service Active Employee Statistical Summary (HAT Report), Pay Period 12, FY 2014," accessed via U.S. Postal Regulatory Commission website at http://www.prc.gov.

31 For example, Fred Smith, Chairman and CEO of FedEx, cited the Postal Service's density as a primary reason behind the development of the company's SmartPost product, which uses the Postal Service for last-mile delivery of packages. Please see cepobserver.com/2010/09/fedex-earnings-implications-for-the-usps.

32 Christensen Associates analysis of commercial package data.

33 For our analysis, we assumed that most of the goods that would benefit from 3D printing as opposed to traditional manufacturing would weigh 1.5 pounds or less. This incorporates the entire weight of the package, including the box and any packing materials. For comparison, many shoes sold on Amazon and other websites have a total estimated package weight of about 2 to 2.5 pounds.

Major national companies and small businesses are already getting into 3D printing.

While massive amounts of in-home 3D printing could reduce USPS deliveries of finished products, the boost in shipments of printing materials could more than make up for it.

scenario analysis to account for differences in the future development of 3D printing. In this paper, we focus on two scenarios that are directly relevant to the Postal Service, as described below. Please see Appendices B and C for more details on the methodology and results of Christensen Associates' analysis.

Centralized 3D Printing: Businesses Sell Finished 3D Printed Goods to Consumers

Given that 3D printing dramatically lowers the barriers to entry for manufacturing, small 3D printing businesses are already cropping up. They primarily use industrial-grade printers, selling high quality customized goods and/or printing services over the Internet. As this burgeoning sector grows, these businesses could increasingly compete on speed. This could lead them to place their printing facilities near shipping nodes, which would allow them to get their products into the delivery stream more quickly. This creates a potential win-win opportunity for these businesses and the Postal Service.

Christensen Associates examined this likely future scenario and projected that it could lead to an 18 percent increase in commercial package volume for the Postal Service. That translates into around $485 million in additional annual revenue, based on 2013 figures. This assumes a medium level of 3D printing disruption. The real-life outcome, of course, will be greatly influenced by technological advancements, changes in consumer preferences, and other factors that are outside the scope of this paper. It also is important to note that the Postal Service's benefit from 3D printing will be tied to the strength of its network. Weakening of the network — through reductions in important features like service frequency, number of delivery points, tracking and tracing services, or pick-up options — could result in the Postal Service forgoing new opportunities in 3D printing.

There is evidence that this scenario is already becoming a reality. For example, innovative new retailers like Shapeways give consumers a way to buy designs and 3D printing services a la carte. Consumers can pick an existing design on Shapeways.com, as well as a preferred printing material, and pay for that design to be printed and mailed to them. Consumers can also submit their own digital files for others to print, or hire an expert to create a digital design based on the consumer's imagination.[34] At locations such as the 3D Heights print store in New York City, people can have their faces scanned and printed onto a wide variety of figurines, and have them shipped directly to their home.[35]

The Postal Service could market itself as a logistics partner for 3D printing businesses located near Postal facilities, giving them a streamlined way to ship products quickly. In addition, the Postal Service has more than 60 million square feet of excess space nationwide, much of which is in mail processing centers.[36] These are industrial facilities that could accommodate the electrical power and ventilation needs of large 3D printers. The Postal Service could lease some of this space directly to 3D printing businesses, making it even easier for them to ship products quickly.

In addition, major national companies are starting to offer 3D printing services to consumers and to small businesses looking to get into the 3D printing market themselves. For example, Amazon recently began a pilot program in which it gives consumers the chance to purchase a variety of 3D printed products from independent designers looking to tap into Amazon's huge customer base.[37] UPS also is conducting a pilot 3D printing service in several major cities across the United States. It aims its 3D printing services primarily at small businesses and entrepreneurs who need to outsource printing of their digital designs. UPS also provides digital design experts for hire on an hourly basis.[38]

Decentralized 3D Printing: People Print Some Goods at Home Instead of Buying Them

Much of the buzz around 3D printing is based on the idea that people could one day use affordable, high quality in-home printers to make many, if not most, of the items they now purchase from retailers. This is highly unlikely. If in-home 3D printers become ubiquitous, they would probably only be used for relatively few items. Nevertheless, this improbable scenario would be massively disruptive to the retail supply chain. It could lead to big cuts in brick-and-mortar and e-commerce sales, and a corresponding drop in the number of commercial packages shipped. (Please see Appendix D for a list of retail sectors that could face disruption.)

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34 Consumers who submit digital designs to Shapeways can also choose to keep those designs private and therefore unavailable for purchase to other consumers.

35 For more information, please see http://www.3dheights.com/.

36 U.S. Postal Service Office of Inspector General, *21st Century Post Office: Opportunities to Share Excess Resources*, Dec. 5, 2011, http://www.uspsoig.gov/blog/21st-century-post-office-opportunities-share-excess-resources.

37 Catherine Clifford, "Amazon Launches Pilot Program Selling 3-D Printed Products," *Entrepreneur*, March 6, 2014, http://www.entrepreneur.com/article/232013.

38 Rakesh Sharma, "UPS May Have Hit Pay Dirt With 3D Printing," *Forbes*, August 19, 2013, http://www.forbes.com/sites/rakeshsharma/2013/08/19/ups-may-have-hit-pay-dirt-with-3d-printing/.

The Postal Service could help usher in a new, brighter era in American manufacturing.

Even though a vast range of products under this scenario would be printed at home instead of being shipped to consumers, every household doing frequent printing would need a variety of 3D printing materials so that they could continue to make the things they need. Analysis from Christensen Associates shows that the increase in shipments of printing materials could actually more than make up for the decline in deliveries of finished products. In part, this is because shipments of printing materials would replace brick-and-mortar purchases that were not shipped through the Postal Service to begin with. At a low level of disruption, this scenario could result in an increase of about 12 percent in the Postal Service's commercial package volume. A high level of disruption could mean a 28 percent increase.[39] Based on 2013 figures, that translates into a $357 million to $1.1 billion annual increase in revenue. However, this scenario is not only highly unlikely, but also highly uncertain. Many hard-to-predict factors could lead to very different outcomes for Postal Service package volume, including the development of a 3D printing material retail network that is largely nonexistent today.

It is important to note that these scenarios are not mutually exclusive, and could happen at the same time. For example, businesses could begin to sell more 3D printed goods to consumers at the same time as people start to use in-home printers to create some items. If this happened, then the effects on the Postal Service in terms of new revenue and commercial package volume would likely be some combination of the effects of both scenarios.

3D Printing's Impact on Logistics

3D printing could have a big impact on the way products move through the supply chain, presenting opportunities for the Postal Service.

- Some manufacturing will move back to the United States.
- Retail storefronts could convert to "shop windows" for manufacturers, keeping only a model in stock and custom printing each item as ordered.
- Warehouses will shift from physical to digital, as spare parts are scanned into vast libraries for future on-demand printing.

Source: Transport Intelligence, *The Implications of 3D Printing for the Global Logistics Industry.*

The Postal Service Could Play a Major Role in 3D Printing

While the Postal Service can significantly benefit from the growth of 3D printing merely by maintaining its existing network and keeping pace with delivery industry changes, it could take concrete actions to enhance or expand its role so that it can benefit even more from 3D printing. It could position itself to become a major player in the emerging 3D printing and delivery market. To get the most out of a 3D printing revolution, the Postal Service will need to match its strategic positioning to the expansion of 3D printing. This would not only be good for the Postal Service, but also good for the economy.

It is no secret that globalization has decimated American manufacturing jobs. Factories in a broad swath of industries have moved abroad, where labor is cheaper. 3D printing has the potential to change that trend, bringing a new wave of manufacturing jobs back to the United States. As small and regional 3D printing businesses proliferate, the full economic benefit of those sales will stay in the United States. If the Postal Service can help these companies compete and thrive, it could help usher in a brighter era in American manufacturing. Below, we propose a few potential strategies and ideas for the Postal Service to consider.

Consider How 3D Printing Could Affect Current Focus and Core Assets

The Postal Service's ubiquitous physical network and unrivaled first- and last-mile delivery capabilities give it a tremendous advantage in serving the 3D printing needs of consumers and businesses. Postal management can take action to ensure that the Postal Service does not lose its current position of strength, and to utilize 3D printing to better optimize future changes. For example:

- As the Postal Service continues to consolidate its processing network, it should guard against any changes that would lessen the value of its first- and last-mile package delivery network. Any weakening of its network could minimize the Postal Service's ability to get the most out of the growth and new developments in 3D printing.

[39] This analysis assumes that the Postal Service would deliver 50 percent of materials shipments. However, as the retail market for 3D printing materials develops, some consumers may buy them from brick-and-mortar stores.

Imagination may be the only boundary for advertisers' use of 3D printing.

La Poste Embraces 3D Printing

In November 2013, France's La Poste began a partnership with 3D printing company Sculpteo to install 3D printers in three Paris-area post offices, as well as to offer an online marketplace where customers can order 3D printed products. Customers can submit their own designs or pick and customize from a catalog with about 40,000 designs. La Poste either delivers the products or holds them at the post office.

La Poste benefits from increased foot traffic and package shipments, and awareness of its embrace of new technologies. Sculpteo is able to better connect with more customers by associating itself with the well-known brand of La Poste, which has a large physical footprint.

Source: Interview with Sculpteo representative.

- According to some observers, 3D printing is creating a new type of logistics company that focuses on delivery, returns, recycling, and other parts of the emerging 3D printing market. In fact, the movement, storage, and home delivery of 3D printing materials alone could become a major new sector of the logistics industry.[40] The Postal Service has many existing assets that could help it play an expanded role in helping products move through the supply chain.[41] Any actions to enhance its logistics capabilities should consider the potential growth of 3D printing.

- The Postal Service will someday need to replace its aging fleet of delivery vehicles. The rapid growth of e-commerce has already led the Postal Service to try to adapt existing vehicles to accommodate large numbers of packages. A 3D printing revolution could greatly exacerbate the need for redesigned, more parcel-ready vehicles.

- The Postal Service could examine the feasibility of renting excess space in postal facilities, such as mail processing centers, to 3D printing businesses looking for places to conduct printing and store printing materials.

Establish New Services Targeted at 3D Printing Businesses

The Postal Service could create a platform for 3D printing that uses its national retail network and last-mile capabilities. By doing so, the Postal Service would create a digital "middle mile" where, at a basic level, designs are sent to the platform and then 3D printed and shipped via same-day or next-day delivery. This could be considered a "hybrid parcel" product, similar to the concept of hybrid mail where digital communications are converted into physical letters. The platform could also include some type of intermediary role for the Postal Service to facilitate the exchange or use of digital designs in a way that protects intellectual property rights. For example, the platform might host "official" designs from toy manufacturers or other companies that are looking to connect with customers in a highly trusted forum.[42]

At minimum, a Postal Service platform for 3D printing could cater to the needs of businesses that want to set up their 3D printing centers near postal facilities, so that the finished goods can drop right into the delivery network. 3D printing will cut the cost of entry for many new businesses looking to get into key markets, as it makes design easier, reduces some production costs, and opens the door to serving emerging niche markets.[43] The Postal Service's nationwide network could be indispensable for the growth of these businesses. The Postal Service could even play a larger role by enhancing its logistics services and helping these businesses prepare the new 3D printed goods for shipment.

A platform for 3D printing might be most feasible if established through partnerships with private sector companies focused on 3D printing, as France's La Poste has done. Partners would be more experienced and better equipped to conduct 3D printing or other innovative services, like 3D scanning. Through partnerships, the Postal Service could tap into this expertise and knowledge without having to develop it on its own. Partners also could help resolve potential liability issues related to intellectual property or safety concerns. Moreover, working with private sector companies already engaged in 3D printing could help the Postal Service to stay current with emerging developments in technology and materials.[44]

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40 Transport Intelligence, p. 4.

41 For more information on how the Postal Service could play an enhanced role in the logistics market, please see U.S. Postal Service Office of Inspector General, *The Global Logistics Revolution: A Pivotal Moment for the Postal Service*, RARC-WP-13-010, June 3, 2013, https://www.uspsoig.gov/sites/default/files/document-library-files/2013/rarc-wp-13-010.pdf.

42 The Postal Service would need to assess what services might be permissible under the 2006 Postal Accountability and Enhancement Act (PAEA), which generally prohibits the Postal Service from offering new nonpostal services. For more information, please see 39 U.S.C § 404(e)(2).

43 Daniel Cohen, et. al., "3-D Printing Takes Shape," *McKinsey Quarterly*.

44 For information on public-private partnerships, please see U.S. Postal Service Office of Inspector General, *Public-Private Partnerships: Best Practices and Opportunities for the Postal Service*, RARC-WP-13-011, June 24, 2013, http://www.uspsoig.gov/sites/default/files/document-library-files/2013/rarc-wp-13-011.pdf.

Think about How Advertisers Could Use 3D Printing to Connect with Customers

The Postal Service could look into how advertisers might use 3D printing to better connect with their customers through the mail. Expanding knowledge of consumer characteristics and preferences is enabling more targeted, cost-effective advertising campaigns.[45] These data could lead to even more customized advertisements using 3D printing. Marketers could send customized product samples or other items tied directly to the individual's interests and preferences. Eventually marketers could even target people who own in-home 3D printers with advertisements that contain scannable codes. If the consumer wants the product in the ad, they simply scan the code to download the digital design to their home 3D printer, which builds the item on the spot. Alternatively, by simply scanning the code customers could have the design printed out at a nearby facility, ready for quick shipping and delivery. With the mass customization enabled by 3D printing and the growing amount of data on consumer preferences, advertisers' use of 3D printing for marketing efforts may be bound only by their imaginations.

Use 3D Printing to Improve Internal Operations

Like any organization, the Postal Service could use 3D printing to improve its internal operations and reduce costs. For example, it could use 3D printers to create replacement parts for its vast fleet of aging delivery vehicles or its wide array of mail processing equipment. In some cases, the companies that originally designed the machines are no longer in business and are therefore unavailable to provide spare parts. This makes it costly and time-intensive for the Postal Service to fix the machines and it is likely that these repairs could be faster and cheaper with 3D printing. By reducing parts expense and downtime, the Postal Service could both save significant resources and improve service.

Additionally, the Postal Service could possibly use 3D printing as a way to facilitate employee suggestions and spread ideas for improving operations across the country. Employees in specific facilities might have ideas on how they could make operations more efficient and simple prototypes could be 3D printed and shared throughout the postal network. Finally, 3D printing might even allow the Postal Service to create customized packing materials for individual items that are oddly shaped or otherwise unsuited for ready-made boxes and packing supplies.

Conclusion

With 3D printing already changing major industries and promising to transform others, it is clear that we are witnessing a critical point in the evolution of technology and manufacturing. Although nobody knows exactly how big the market will get or what direction it will take, 3D printing is here to stay. It could have a major impact on the Postal Service and countless other organizations in the United States and across the globe.

As 3D printing democratizes production and design, it could become a fierce engine of economic growth and job creation. We have not yet begun to see the rise of new businesses taking advantage of this technological revolution, and we are only in the early stages of new citizen demand for mass customization. By establishing a role in the 3D printing market, the Postal Service could put a compelling 21st century twist on its historical mission to serve citizens and facilitate commerce.

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[45] For more information, please see U.S. Postal Service Office of Inspector General, *Enhancing the Value of Mail Follow-Up: Discussion Forum Recap*, RARC-IB-14-001, April 3, 2014, http://www.uspsoig.gov/sites/default/files/document-library-files/2014/rarc-ib-14-001.pdf.

Appendices

Appendix A: 3D Printing Case Studies

3D Printing Case Studies

This appendix features examples of innovative ways people are using 3D printing.[46]

Prosthetic Limbs

A carpenter in South Africa collaborated with a design specialist in Washington State to replace four fingers on his right hand that he lost in an accident. MakerBot provided both of them with a desktop 3D printer, and they began trading ideas and tweaking the design of the mechanical fingers. The 3D printers allowed them to shorten the prototyping time from weeks to just 20 minutes, as they traded files and tested new designs from across the world. After the carpenter's successful creation of his own 3D printed fingers, which was dubbed "Robohand," he provided the design files online for others to access.

Figure 6: Young Boy Using Robohand

Source: MakerBot Industries.

The parents of a 5-year-old boy who was born with no fingers on his right hand soon contacted the carpenter to learn more about the Robohand. The boy's family was unable to afford traditional prosthetics, and the boy would quickly outgrow such expensive devices anyway. 3D printing offered them an opportunity to create custom-fit artificial fingers that allow the boy to grasp and hold objects for only $150 — a fraction of the cost of traditional prosthetics, which can cost more than $10,000 per artificial finger.[47]

Figure 7: 3D Printed Prosthetic Limbs

Source: MakerBot Industries.

The Robohand design has been downloaded thousands of times by people around the world and even adapted for other needs. For example, a teenage boy in Sudan lost both of his arms when a bomb dropped on him while he was tending his family's cows. This boy received a 3D printed prosthetic arm based on the Robohand design, which only cost about $100 (not counting the cost of the 3D printer and computer). The organization that provided the 3D printed arm is now looking to use 3D printers to help amputees in other conflicts across Africa and the rest of the world.[48]

Customized Eyewear

Traditional eyewear is mass manufactured, limiting the ability to adjust the frames to better fit people's unique faces. However, Protos Eyewear is offering 3D printed eyeglass frames that are manufactured to each individual's facial structure. Customers submit two photographs of themselves — one from the front and one from the side — and select a frame style. If customers need prescription lenses, they can also submit the necessary prescription information to Protos. The company then uses software to modify frame designs to customers' faces based on the photographs they submit. The end goal is a pair of glasses that fits the exact contours of each customer's face, to provide the best fit and comfort possible.[49]

Figure 8: 3D Printed Eyewear

Source: MakerBot Industries.

Historical Artifacts

Many historical artifacts are extremely fragile and cannot be moved. They are often

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[46] There are many examples of 3D printing applications available online, including on the MakerBot website at http://www.makerbot.com/blog/category/makerbot-stories/ and the Stratasys website at http://www.stratasys.com/resources/case-studies/.

[47] "Mechanical Hands From A MakerBot: The Magic Of Robohand," *MakerBot*, May 7, 2013, http://www.makerbot.com/blog/2013/05/07/robohand/ and "MakerBot and Robohand," MakerBot, May 8, 2013, http://makerbot-blog.s3.amazonaws.com/wp-content/uploads/2013/05/RIs_MakerBot_Robohand_May2013.pdf.

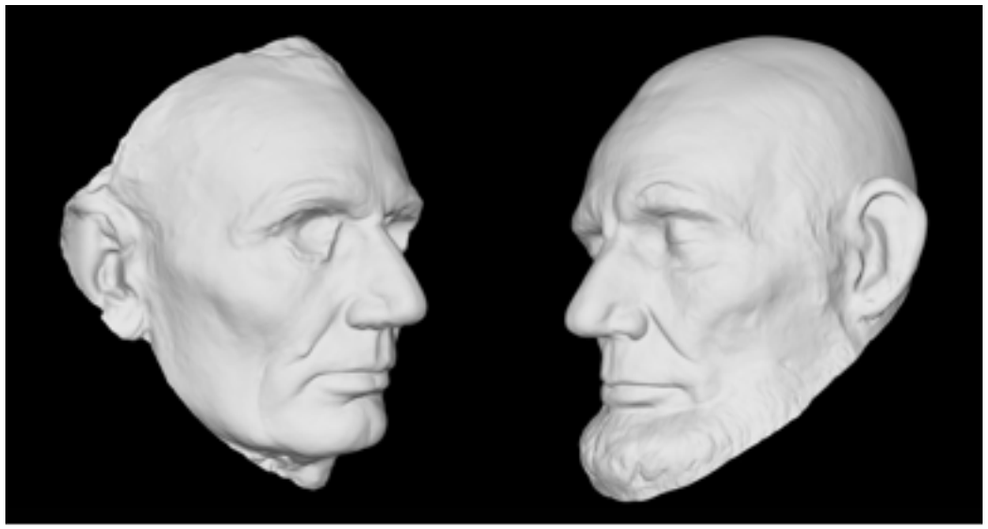
[48] "MakerBot Stories, Project Daniel Takes Robohand to Sudan, *MakerBot*, Januray 30, 2014, http://www.makerbot.com/blog/2014/01/30/project-daniel-takes-robohand-sudan/.

[49] "Eyewear 3D Printed to Fit You," *Protos Eyewear,* 2014, http://protoseyewear.com.

limited to only one museum or occasional traveling exhibits. If you are not able to visit the specific museum that displays an artifact, you likely will never see it. However, 3D printing is opening up new possibilities. For example, engineers recently scanned the remains of King Tutankhamen and created a 3D printed replica. Because the engineers followed a painstaking process of capturing every detail, and due to 3D printing's layer-by-layer precision, the 3D printed replica is allegedly virtually indistinguishable from the actual mummy.[50]

The Smithsonian can only display about 1 percent of its overall collection of 137 million objects, artworks, and specimens. The millions of other artifacts are left outside the public's view. To bring this vast collection to the public, the Smithsonian has begun 3D scanning selected objects and releasing the image files to the world. Anyone with a computer and access to the Smithsonian's public web portal can download these 3D scans and, if they also have access to a 3D printer, have the scans printed out. Educating the public is not the only benefit of this endeavor — 3D scanning and printing could also allow researchers to leave original artifacts undisturbed because all the researchers need to do is scan the object or the surrounding site, and then print it out later.[51]

Figure 9: 3D Scans of Abraham Lincoln's Life Masks



Source: Smithsonian Institution.

[50] Brooke Kaelin, "A 3D Printed Replica of King Tut's Mummy," *3D Printer World*, August 3, 2013, http://www.3dprinterworld.com/article/3d-printed-replica-king-tuts-mummy.

[51] "About Smithsonian X 3D," *Smithsonian Institution*, http://3d.si.edu/about, and Eric Mack, "Smithsonian Now Allows Anyone To 3D Print (Some) Historic Artifacts," Forbes, November 13, 2013, http://www.forbes.com/sites/ericmack/2013/11/13/smithsonian-now-allows-anyone-to-3d-print-some-historic-artifacts/.

Appendix B: Details on Analysis of Commercial Packages Supply Chain Volumes

Details on Analysis of Commercial Packages Supply Chain Volumes

For this project, we contracted with Laurits R. Christensen Associates, an economic consulting firm with in-depth knowledge of U.S. Postal Service operations. Christensen Associates has worked on postal issues since 1981 and performs assessments on postal data systems for the Postal Service itself.[52] This appendix provides some details on the process Christensen Associates used to assess the impact of 3D printing on the Postal Service's commercial packages supply chain.

For this analysis, Christensen Associates used a snapshot of the fiscal year 2013 (October 1, 2012 to September 30, 2013) commercial packages supply chain, with a focus on parts of the supply chain that would be affected if a 3D printing revolution took place. If a 3D printing revolution does not take place, then these effects would be less significant. To the extent possible, Christensen's analysis ignored the reasons for 3D printing's increase, be it technological advancement, societal trends, a combination of both, or other factors entirely. Its analysis also ignored the speed of 3D printing's advancement.

Christensen based its analysis primarily on data from the Postal Service's Electronic Verification System (eVS). These data could be considered commercially sensitive, so any raw numbers, mailer-specific, or other highly detailed information from eVS is not included in this paper. Because eVS tracks critical information about each individual package traveling along the Postal Service's portions of the commercial packages supply chain — such as piece weight, origin entry location, and destination location — the database offers an examination of commercial package flows at an unprecedented level. Overall, the eVS tracks about 70 percent of all commercial packages delivered by the Postal Service. The database also provides information to determine the revenue associated with each package tracked.

Christensen also assessed the weight profile of the Postal Service's commercial packages supply chain. To do so, it grouped most of the mailers listed in the eVS into 18 categories based on their primary business function. Nearly all of these categories were specific to a particular type of product, such as clothing, jewelry, pharmaceuticals, and so on. Christensen determined which of these categories were associated with goods that could be affected by developments in 3D printing. For two categories that were non-specific ("Courier/Fulfillment" and "National Retailer"), Christensen used data from the U.S. Census Bureau's Annual Survey of Retail Sales to identify related product codes that would be likely to use the commercial packages supply chain and be affected by 3D printing, and then incorporated calculations from this Census survey information into its assessment of the eVS data.

To create a baseline for comparing the potential effects of various 3D printing scenarios, Christensen quantified the entire U.S. commercial packages supply chain, including giving the Postal Service "credit" for packages that originate with private delivery firms but are handed off to the Postal Service for final delivery. This assumption reflects the fact that advancements in 3D printing that increase the number of commercial packages shipped will affect both the packages that the Postal Service handles end-to-end as well as the packages from private delivery firms for which the Postal Service handles final delivery. Christensen derived volumes for private delivery firms from publicly available sources.

Through these steps and other calculations, Christensen created a snapshot of the entire U.S. commercial packages supply chain for fiscal year 2013. It then determined volumes for lightweight (1.5 pounds or less) and heavy (more than 1.5 pounds) packages, and further split the lightweight volumes into groups that would likely be affected by 3D printing and those that would likely not be affected. With this baseline established, Christensen created assumptions of impact for varying levels of intensity of 3D printing disruption (low, medium, and high) for each of the scenarios described in the body of this paper. Finally, Christensen created revenue estimates for each scenario based on the current class mix across packages at 2013 actual postal prices.

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52 Please see the Christensen Associates website at http://www.lrca.com/postal/ for more information.

Appendix C: Potentially Simultaneous Scenarios for 3D Printing

Potentially Simultaneous Scenarios for 3D Printing

The figure below summarizes how two potential 3D printing revolution scenarios could affect the Postal Service. Each scenario results in an increase in annual revenue due to increased package shipments. The scenarios are not meant to be mutually exclusive, as it is easy to envision a world in which people buy some 3D printed finished products from businesses while also printing some items at home. The estimates given in the figure show the range of potential annual revenue growth, depending on how much 3D printing disrupts the status quo.

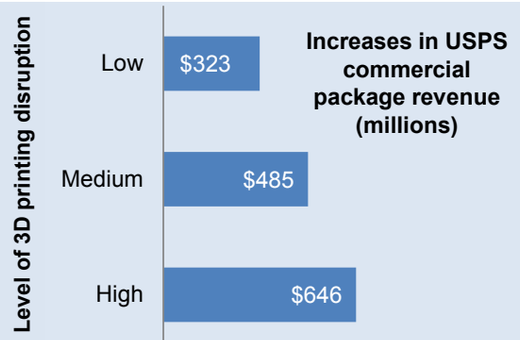
Figure 10: New Revenue from Two Potential 3D Printing Scenarios

3D PRINTING COULD BE A POSTAL BOON

Under two potentially simultaneous scenarios, a 3D printing revolution could lead to more shipments of small, lightweight packages — the types of packages the Postal Service specializes in handling. Depending on the scenario and level of disruption, 3D printing could boost the Postal Service's package revenue by $323 million to $1.1 billion per year. These estimates are based on 2013 package volume data.

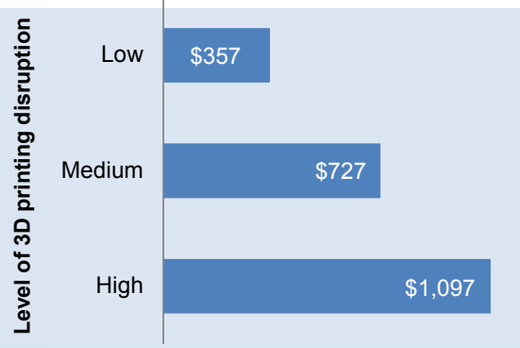
USPS AS 3D PRINTING HUB

Small and regional businesses 3D print products at or near Postal Service shipping nodes before entering products seamlessly into the mail. These businesses would likely compete on speed, so streamlining deliveries could help them to better serve customers — while also boosting package volume for the Postal Service.



PRODUCTS PRINTED AT HOME

People use in-home 3D printers to produce many of their items, rather than buying final products from retailers. While this could reduce both deliveries of finished products and brick-and-mortar purchases, deliveries of printing materials could surge, potentially giving a boost to the Postal Service. This scenario could be very profitable, but a slew of uncertainties and potential risks make it highly unlikely.



Source: USPS OIG graphic based on data from Christensen Associates.

Appendix D: Retail Sectors that Could be Disrupted by In-Home 3D Printing

Retail Sectors that Could be Disrupted by In-Home 3D Printing

If Americans begin using in-home 3D printers to manufacture many of the products they now buy from retailers, it could affect nearly 28 percent of the entire retail trade industry, with as many as 45 billion products potentially being printed at home instead of purchased at the store.[53] It is important to note that the likelihood of such a massive disruption is very low. Even if in-home 3D printers take off, many people would likely only print a limited number of items. Figure 11 outlines the sectors most vulnerable to 3D printing disruption, as well as the size of those sectors.

Figure 11: Retail Sectors Vulnerable to 3D Printing Disruption

VULNERABLE TO DISRUPTION

If a broad swath of Americans were to use in-home 3D printers to create many of the items they need instead of buying those products from retailers, it could turn the retail sector upside down. More than 900,000 retailers with some $1.16 trillion in sales could see some of their business supplanted. The sectors and their sizes are outlined below.

Retail sector	Number of businesses	Total sales (millions)
Miscellaneous retailers	198,146	$48,611
Clothing	187,528	$190,960
Gift, novelty, and souvenirs	103,351	$25,355
Electronics	103,214	$143,850
Sporting goods	61,453	$38,985
Jewelry	53,781	$44,979
Auto parts	45,554	$162,322
General merchandise	37,518	$408,080
Hobby, toys, and games	36,888	$26,059
Shoes	30,853	$25,804
Sewing, needlework, and piece goods	18,930	$10,189
Household appliances	16,998	$14,346
Musical instruments	11,731	$6,314
Office supplies and stationary	10,958	$9,526

Source: USPS OIG graphic based on Christensen Associates analysis of 2011 retail sales data.

53 Based on analysis from Christensen Associates, using simplified assumptions about the average unit price in the retail trade industry.

OFFICE OF
INSPECTOR
GENERAL
UNITED STATES POSTAL SERVICE

U.S. Postal Service Office of Inspector General
1735 N. Lynn Street
Arlington, VA 22209

Telephone: 703-248-2100
www.uspsoig.gov

For media inquiries, contact Agapi Doulaveris
Telephone: 703-248-2286
adoulaveris@uspsoig.gov