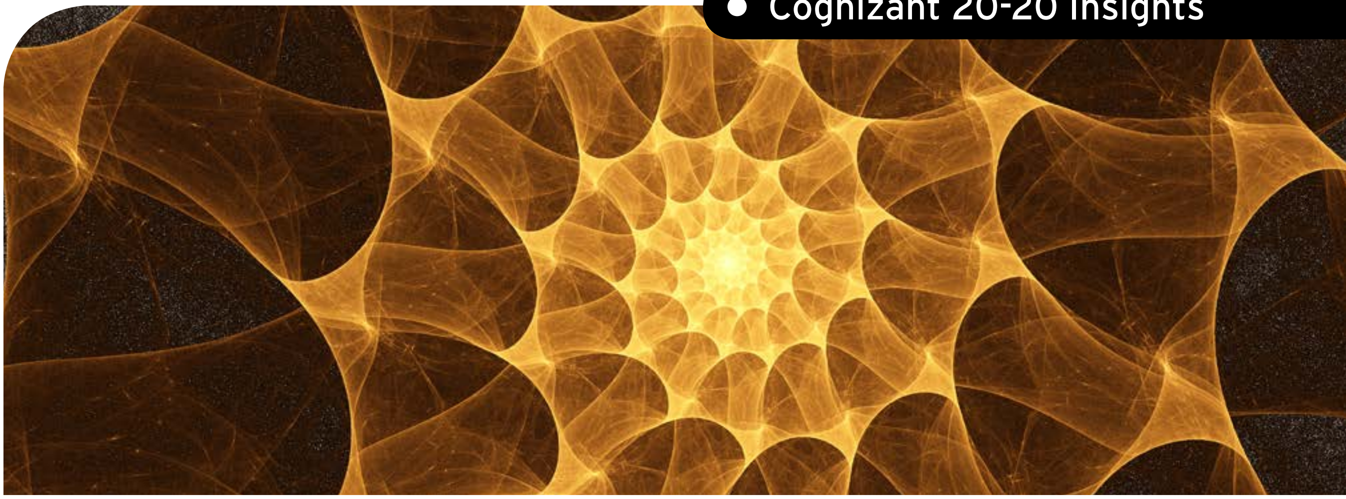


Printing the Future: From Prototype to Production

To reap the full benefits of additive manufacturing, organizations need a strategic plan and roadmap that ties 3-D printing technologies and techniques to key business case imperatives, accelerating their time to market by reaping essential product design, operational and market differentiation advantages.

Executive Summary

Additive manufacturing (AM) has gained prominence as one of the leading transformative technologies within the manufacturing space. There are signs that additive technologies are evolving from mere prototyping to applications that are used to validate designs, in essence becoming a core component of the manufacturing process. By harnessing additive technologies, industry leaders worldwide can reduce the time to market of their products, improve quality, shorten their supply chains and achieve production at scale.

Getting there, however, has its share of challenges. This white paper outlines the key obstacles and associated opportunities that surround AM adoption. Most manufacturers still see AM as a niche opportunity associated with prototyping and remain skeptical about moving the technology to assist with volume production. To help overcome these concerns, this white paper introduces a maturity model and an assessment framework to enable manufacturers to make informed decisions on AM adoption for volume production.

Through this framework, manufacturing companies can understand the implications of AM adoption on the business and identify potential deployment areas. The framework also offers a direction to choose potential areas of focus, depending on the business impact and readiness of the organization's infrastructure.

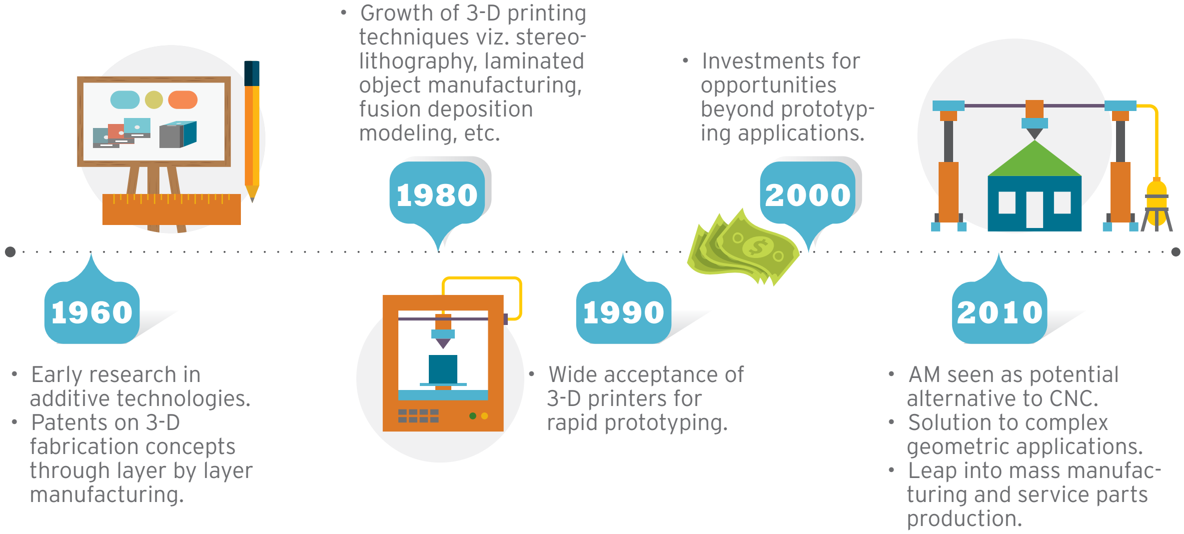
The Evolution of Additive Manufacturing

AM is the process of making a three-dimensional (3-D) object from a computer-aided design (CAD) model through an additive method, where layers of material are layered on top of others. 3-D printing differs from traditional machining techniques, which rely on the removal of material by methods such as machining, cutting, drilling, etc.

Broadly put, these processes[1] include:

- Fused deposition modeling: extrusion techniques.
- Granular materials binding: selective laser sintering or direct material laser sintering.
- Laminated object manufacturing.

3-D Printing's Evolution



Source: Cognizant
Figure 1

- Photo-polymerization: stereo lithography or digital light processing.

The biggest change within the AM space is in its end use. Historically, AM was used primarily to create visualization models, prototypes for fit and function testing, as well as for patterns for prototype tooling. Figure 1 depicts the evolution of 3-D printing applications, revealing where organizations are now focusing their energies – for example, on making parts that go into final products.[2]

AM Opportunities and Challenges

Leading manufacturers have begun to introduce AM into mainstream use – for instance, leading diversified manufacturers such as 3M and General Electric are leveraging 3-D printing in prototyping as well as in direct parts production. GE's Aviation division has deployed 3-D printing technology to print nozzles for its LEAP engines, which has reduced material waste, made parts lighter and yielded significant fuel savings for airlines. By 2020, GE Aviation projects that it will have printed more than 100,000 additive parts[3] and used AM technologies and techniques to cut the production costs of specific parts, such as ultrasound probes, by up to 30%.

Airbus plans to produce aircraft parts weighing 30% to 55% less than existing components, while reducing raw material used by 90%. The latest Airbus A350 aircraft has more than 1,000 parts printed, which has enabled the company to reduce production time and costs.[4] Thanks to 3-D printing, the production time for Ford's cylinder head, used in its fuel-efficient EcoBoost engines, has been reduced from approximately five to three months, shaving off 25% to 40% of production time.[5] Similarly, German auto giant BMW achieved significant cost and time savings by using AM for jigs and fixtures rather than conventional CNC machining.[6]

Gartner forecasts 3-D printer shipments will more than double every year between 2015 and 2018. Overall, end-user spending on 3-D printers is expected to increase from $1.6 billion in 2015 to about $13.4 billion in 2018.[7] McKinsey predicts 3-D printing will generate an economic impact of $230 billion to $550 billion per year by 2025, the vast majority originating from consumer uses and direct manufacturing applications.[8]

Given the upside, manufacturing hubs in the European Union and China have formed councils involving government, universities and corporations to boost AM skills.

As 3-D printing continues to grow, new processes and technologies are changing the shape of the industry. 4-D printing, characterized by structures that can be preprogrammed to respond to stimuli and change their shapes into desired patterns, is emerging as the next frontier of innovation. This technology has far-reaching impact on a wide variety of industrial as well as consumer products that need to change behavior in response to heat or moisture. Similarly in healthcare, biocompatible components such as cardiac tubes can help create new types and forms of products which were not possible before.

The adoption of AM is expected to impact every stage of the manufacturing value chain, starting with prototyping and extending through order fulfillment. This is expected to yield a wide range of benefits (as outlined in Figure 2).

Clearly, AM holds huge potential. However, each organization needs to thoroughly understand the challenges and evaluate the costs and potential benefits of adopting AM for its own unique requirements.

AM Adoption Challenges

While AM technologies have evolved quickly over the past two decades, many issues remain in terms of materials, processes, applications and commercialization.

4-D printing, characterized by structures that can be preprogrammed to respond to stimuli and change their shapes into desired patterns, is emerging as the next frontier of innovation.

Complex parts and geometries will necessitate that AM is carried out in multiple stages and iterations to produce the final parts. Occasionally, AM requires final post treat-

AM's Alluring Advantages

Flexibility in Design	• Increase in focus on functionality and innovation compared with conventional manufacturing where there is a greater need to confine manufacturability to providing enhanced functionality. • Enables flexible production and mass customization as designs can be changed quickly. • Ease in redesign without downstream impact. • Ability to custom design final assemblies at the dealerships.
Optimal Capacity Planning	• The integration of CAD with manufacturing systems provides the ability to better plan capacity, manage and automate factory loads, offer accurate delivery dates to customers and schedule factory capacity.
Shorter Time from Design to Pilot Batch	• Reduced dependency on computer-aided engineering (CAE) systems to predict performance under actual conditions since the approach can be used for experimental purposes. • Reduced lead time from design to prototyping and ability to produce finished products with material properties often better than cast applications.
Efficient Production	• Easier manufacturing of complex products that combine various materials, concurrently (i.e., enabling the integration of components with varying levels of toughness, flexibility, temperature resistance, flexibility, color and transparency). • Eliminates the cumbersome process of planning effort and set-up time. • Eliminates the waste of raw material by "adding" or building-up parts in layers. • Raw materials can be reused for multiple builds, keeping a check on their properties. • Reduces environmental impact for manufacturing sustainability. • One machine – many product lines: produces variety of products using the same set-up.
Lean Supply Chain	• Minimizes the amount of material used to produce products, resulting in reduced procurement efforts and length of supply chain. • Enables small batch production faster, thereby reducing overall inventory costs. • Reduces the size of components with its potential of applications in vehicles and aircrafts, thereby reducing fuel consumption and emissions. • Reduces unit cost of product and lead time associated with tooling with on-demand manufacturing. • Spare parts production on demand at the distribution leg, thereby reducing service lead time. • Faster packaging through direct production of containers.

Figure 2

ments before they can be used. Existing CAD/E systems have limited functionality to model complex geometries made of functionally gradient materials and biological materials. Integration with computer-aided manufacturing (CAM) will require new capabilities such as additional parameter support for cutting depth, feed, etc.

The shift in control of production will also pose serious infringement issues that cannot be directly addressed by current intellectual property (IP) strategies. Current IP protection law in the industrial sector states that it is illegal to replicate products by any means for commercial gain. Hence, designers, manufacturers and end-consumers need to be aware of the way in which IP rights are created, either as design rights which protect the shape of products, trademarks that protect branding or patents for innovation.

Another huge challenge facing manufacturers and designers working with AM technologies is the relative lack of standardization across the industry concerning materials and processes. Establishment of related standards for AM remains very much a work in progress.

While many of these technical challenges are the areas of active research, the primary challenge remains the incorporation of AM technology into conventional volume production. The framework proposed in the subsequent sections aims to help companies evaluate the opportunity and structure an action response to move to AM volume production.

Our Additive Manufacturing Adoption Framework

Our approach, called Cognizant's Additive Manufacturing Adoption Methodology $C(AM)^2$, consists of three phases:

- **Assess business impact:** Organizations should evaluate AM adoption implications on the business and identify potential areas for implementation. This should ideally be an outcome of the business drivers within an industry segment. Based on our experience working with manufacturing organizations, we've developed a set of initial recommendations to help organizations within various industry segments get started assessing business impact (see Figure 3).

3-D Printing's Business Impact

Industries in Focus	Typical Candidates for AM	KEY BUSINESS DRIVERS: Economy of Scale	Design Flexibility	Product Customization	Lean Supply Chain	Green Mfg. (Sustainability)	Shorter Lead Time: Design to Mfg.
Aerospace	• Aero-Engine Components • Repair & Overhaul	Low	High	High	Medium	Medium	Medium
Automobile	• Metal & Polymer: › Direct Parts › Prototyping › Repair, Service Parts	Medium	High	High	High	Medium	Medium
Industrial Machinery	• Precision Components • Repair, Service Parts	Low	High	High	Medium	High	High
Medical	• Medical Devices • Implants • Prosthetics	Low	High	High	Low	Medium	Low
Electronics	• Electronic Components: › Transistors, Printed Applications, etc. • Displays	High	Medium	High	Medium	High	Medium

High Medium Low

Figure 3

Deconstructing AM Maturity

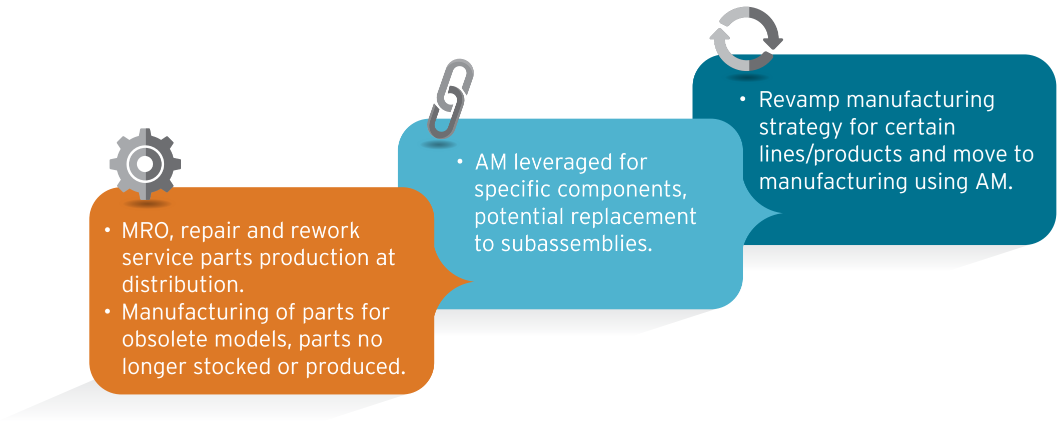


Figure 4

After assessing the impact of AM on the business, manufacturers can shortlist potential areas for implementation. For that, the manufacturing enterprise must understand the functional and nonfunctional IT requirements to integrate AM with existing CAX/ERP/MES systems.

- **Evaluate level of adoption:** The paper classifies AM adoption maturity into three broad categories – packaging and service parts, components production and core manufacturing. Depending on their process maturity, the impact on the business and readiness of infrastructure, manufacturers can then choose to implement AM where they are most evolved and impactful (as shown in Figure 4).

To expand AM from mere prototyping to actual part production, organizations must evaluate the operational level impact of adopting an additive technology strategy. Areas to consider include:

- **Design and material selection:** Understanding the intended application and needed material characteristics is important to the material selection process. Also, the rate of production/speed of printing is dependent on the speed at which the printer head can extrude the raw material used. While 3-D printers can print in a multitude of materials ranging from plastics to stainless steel, few are capable of allowing the user to switch back and forth between modes and materials. Primarily tensile strength is the parameter that determines material strength (i.e., the pressure the part can withstand), but for extreme application toughness, durability and temperature must also be considered. Design and simulation parameters, therefore, will change.

- **Production:** Even through the technology is able to produce high-quality products, adding printers to the production line will impact the existing layout, routing, set-up timing, part storage, etc. Changes are therefore required to existing CAM systems that are capable of generating code for computer numeric control (CNC) machines that work on the principle of subtractive manufacturing. Additional treatments, or finishing, must be performed on the printed parts since tolerance levels are typically low. Mixing various materials with different shelf lives to achieve the desired properties is critical. As a result, unmanned printers require frequent maintenance.

3-D printers can print in a multitude of materials ranging from plastics to stainless steel, few are capable of allowing the user to switch back and forth between modes and materials.

- **Supply chain:** AM requires a dedicated and controlled environment for storing and retrieving raw materials. The inbound supply will be redefined for high-grade materials, but in general 3-D printing can process locally-sourced materials, reducing procurement lead time. Changes are required to inventory levels, intermediate storage facilities, dedicated shipments and networks. Production and assembly of components and finished goods on demand reduces the length of the outbound supply chain. Tighter integration with all production processes from sales and operations planning (S&OP) through project management is required, as well as greater collaboration between the customer and suppliers.

- **Quality management:** Well-known, established methodologies exist for quality inspection on parts using conventional manufacturing methods. Complex geometries produced through AM will not require the existing quality stages such as tolerance checks, fitment analysis, etc. on individual parts and on the assemblies. But complex geometries for parts using AM envisage internal voids and structures not accessible from outside. As a result, conventional testing concepts including yield strength and ultimate tensile strength require a different test environment.

Assessing adoption for core manufacturing is a long-term strategy and requires thorough analysis of business strategy, operations and planning, and organization changes. It requires complete redesign of supply chain and production layout. Whereas manufacturers can easily deploy AM for repair or rework with minimal impact to the production set-up in the short term, they should use these pilots to evaluate the longer-term benefits across the enterprise. Depending on the initial effectiveness of AM, manufacturers can then fine-tune their expansion plans based on their intrinsic maturity levels.

- **Defining an implementation roadmap:** An implementation roadmap for 3-D technologies requires the development of a high-level plan that weaves together all the aforementioned areas to facilitate a successful transformation. Once the desired level of maturity is assessed and constraints are identified, a detailed roadmap can be devised. The critical considerations while defining a roadmap are the business impact and the supply chain changes. The roadmap must be phased according to required adoption timelines, taking into account the organization's level of process maturity, existing standardization and stakeholder readiness.

The initial phase should focus on monitoring the production technology and piloting significant length runs on the products to test the quality of newly introduced materials. Moving to part production will cause some changes to product design but will emphasize material management, production processes and quality.

In the next phase, production capability will be extended to components or subassemblies. The decision for this investment will be linked directly to the market and product characteristics. The types of products that are suitable for AM adoption are those with a degree of customization and of low volume. This will shift design stage focus to provide additional flexibility in manufacturing and will eliminate the tooling, production gauges and fixtures design. Design optimization will be needed to evaluate possible production scenarios, machine consistencies, materials to provide better properties and capabilities. Only when the desired maturity is reached, do we recommend manufacturers bring additive technologies to core production. The entire supply chain must be redesigned to accommodate the changes and modifications to the underlying IT landscape will be required to support this strategic move. Typical changes would include upgrades in manufacturing execution systems to adapt to AM techniques and printers. Also needed are upgrades to product lifecycle management (PLM) systems to accommodate accelerated product introduction and changes to prototyping phases.

The timelines for implementation and assessment parameters vary from industry to industry, and depend on the level and complexity of AM adoption.

The roadmap must be phased according to required adoption timelines, taking into account the organization's level of process maturity, existing standardization and stakeholder readiness.

Looking Forward

AM technologies have the potential to power a new industrial revolution. To do this, manufacturers must define an AM strategy and roadmap based on a solid business case to fully realize its operational benefits. As noted above, the aerospace, automotive, medical and electronics industries are most promising for additive manufacturing considering the impact on the key business drivers.

To start with, manufacturers can create the foundation to embrace AM by:

- Identifying the most appropriate materials and processes for the product requirements.
- Understanding costs associated with using printers.
- Benchmarking third-party vendor technologies.
- Assessing the impact of cultural changes AM would entail.

The impact of AM adoption varies in each industrial segment, and hence organizations must evaluate the benefits of AM adoption based on their unique business challenges and supply chains to reap faster growth. Even though there is no standard way to implement additive technologies, the high-level framework presented in this white paper offers implementation guidance to help organizations more painlessly achieve the market advantages this potentially disruptive technology offers.

Footnotes

[1] Institute of Defense Analysis — Emerging Global Trends in Advanced Manufacturing.

[2] Ibid.

[3] http://www.ge.com/stories/advanced-manufacturing.

[4] http://3dprint.com/63169/airbus-a350-xwb-3d-print/.

[5] http://mashable.com/2013/06/09/ford-3d-printing/.

[6] http://www.stratasys.com/resources/case-studies/automotive/bmw.

[7] http://www.gartner.com/newsroom/id/2887417.

[8] http://www.mckinsey.com/insights/business_technology/disruptive_technologies.

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About Cognizant

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