Additive Manufacturing as a Disruptive Technology

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Preface

Last summer I was invited to give a presentation on Additive Manufacturing to the Standing Committee on Defense Materials Manufacturing and Infrastructure (DMMI) of the National Research Council/National Academies. The presentation opened their workshop on affordable, low-volume manufacturing. The material below is a summary of that presentation. The prepublication report on the entire workshop, *Limited Affordable Low-Volume Manufacturing: Summary of a Workshop*, is available on their website. My presentation slides are also now available on the Athena Alliance website.

Additive Manufacturing in a Changing Economy

Additive manufacturing (aka 3D printing) is a new manufacturing process where materials are deposited ("printed") layer by layer to create a three dimensional object. As such, additive manufacturing is often viewed as a replacement for traditional manufacturing. However, this is not the appropriate way to frame any economic discussion of additive manufacturing technology. Instead, we need to focus on additive manufacturing as a disruptive technology and put the technology into the context of macro forces at work in the economy.

Let us begin with these macro forces changing the economy:

> *The rise in the intangible economy*. Over the past three decades, there has been a shift in the factors of production away from tangible assets (such as land and capital) to intangible assets (such as knowledge). Knowledge is embedded not just in patents and

copyrights but also in workforce skills, social relationships, and organizational processes. This creates a whole new series of factors in production that drive competitiveness. The level of investment in intangibles now exceeds investment in plant and equipment.

The fusion of manufacturing and services. The traditional breakdown of manufacturing and services does not make sense anymore, as they are intertwined. Apple is a prime example with the combination of a product (iPods and iPads) with a service (iTunes). Value-added is no longer found in just the manufacturing process (due to economies of scale) but in the services/knowledge component. That component can be a separate product (after sales service) or is more commonly seen (but often not recognized) as the high level of knowledge embedded in the products.

The change of the innovation process. The generally view of the innovation process is linear: basic research feeding into applied research followed by technology development. While this might have been true in the industrial age, a different view of innovation has emerged in the past decade. Innovation is driven by user needs, with bottom up, design-based thinking approach involving problem solving and rapid prototyping. I see this more as a "stew pot" model where multiple ingredients, including technology, are mixed together -- rather than the development and refinement of a specific technology.

The latest step in globalization, "Globalization 4.0". Globalization 1.0 was characterized by growth in international trade. In Globalization 2.0, the supply chain became global, but production remained specialized in different regions. In Globalization 3.0, the complete economic structure became global, and the focus was on harmonizing the economic rules. In Globalization 4.0, production will be brought back to a very local system, though still within the global context.

Disruptive technologies

Disruptive technologies fit into these changes in the macroeconomic forces. What is a distributive technology? Let me use the example of the steam engine and the railroad. The steam engine was initially designed to be used as a pump based on linear motion. As such, it had limited application. It wasn't until the pump's linear motion was converted to rotational motion that steam power became ubiquitous. The result was both locomotion (the railroad) and manufacturing power (the factory). Remember that both railroads and machine production existed before the steam engine (mostly powered by animals). But it was this expanded source of power that disrupted the entire economic structure.

The development of the railroad system continued this disruption with three major impacts:

New markets opened. Railroads transformed local markets into a national market. In part because of price wars due to overbuilding of railroad lines, retail companies (such as Sears) could reach a national customer base.

New industries were created. Building and running the railroads also increased the demand for machine-based manufacturing (for locomotives and railway cars) and new materials (steel).

Management structures changed. Management changes were needed to operate trains across the United States. Alfred Chandler's book *The Visible Hand: the Managerial Revolution in American Business* chronicles this shift from family management to professional management. I would argue also that the shift from a "spoils" system to a professional civil service in the public sector was parallel to and driven by the rise of professional management in the private sector.

The lesson from the steam engine and railroad is that a disruptive technology has two main characteristics:

• it allows for something new (not just an improvement on something already in existence), and

• it has spillover effects that create new activities.

Additive manufacturing as a disruptive technology

Additive manufacturing is a perfect example of a disruptive technology using this definition.

Additive manufacturing started as something else. It began as a technique for rapid prototyping. As the technology matured, both in the process and in its available, it moved from prototyping to actual production.

It allows for something new:

Manufacturing new shapes that could not be manufactured before. For example, additive manufacturing techniques can create prosthetics that would have been prohibitively expensive using conventional techniques.

Harnessing the new use of materials. Additive manufacturing can combine materials in ways that were not possible before --for example, making a single piece of variable density. Image the possibilities of a baseball bat made with variable density, hard at one end, soft at the other.

Requires new design processes. Once the materials have changed, the design process needs to change as well, and a completely different approach to manufacturing is called for. This is a hallmark of a disruptive technology.

Additive manufacturing fits directly into and reinforces the macro forces discussed above:

Additive manufacturing is based on knowledge, not physical assets. As a result, the manufacturing approaches change: manufacturing can now be accomplished anywhere there is a suitable printer.

The economic structure changes. Manufacturing and service (design/customer problem solving) are now fused together as "production" becomes less about economics of scale and more about customizing the product to meet a specific need.

The innovation model changes. Manufacturing becomes more bottom-up, as designs can be changed at the user end rather than only at a large manufacturing company's design department.

Additive manufacturing enables Globalization 4.0. Production can now be localized. But this does not necessarily mean home production. However, handling and storage of raw materials can be difficult, so the model may be better suited to a regional production site; for example a local hardware store printing individual screws as the customer needs them.

Policy implications

What does this mean for policy, specifically for defense?

First, it may change the design and function of weapon systems as new production capabilities change the design process.

Second, military readiness issues change as additive manufacturing development creates an ability to produce parts and entire weapon systems on demand and at site.

Third, as control of raw materials becomes more important, key strategic considerations may shifts from control of the production site to the raw materials site.

Fourth, existing mechanisms to control weapons proliferation, such as the International Traffic in Arms Regulations (ITAR), may not be as relevant/effective/enforceable when the design can be sent anywhere in the world and production can be localized.

In summary, spillover effects from additive manufacturing will occur, but we do not know where the technology will lead us. We do know that it will allow us to do things we have not been able to do before. The challenge right now is to monitor and understand how that new capability affects our economic and national security.