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The Evolution of Rapid Production: How to Adopt Novel Manufacturing Technology

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Abstract: This research focuses on the evolution and adoption of rapid production. We investigate the ways novel rapid production technology offers competitive advantage to companies, and argue that benefiting from this technology requires significant changes in business beyond manufacturing. The study is centered on core areas that need to be addressed when adopting such rapid production technology: business models, processes, IPR, industry characteristics, product/service transition, logistics and materials. Of note, whereas 3D printing has been praised as the "next big thing" in personal fabrication, it is just a stage in an ongoing transition from rapid prototyping toward rapid manufacturing. In the study, we establish and discuss two frameworks: 1) evolutionary steps in rapid production, and 2) key business imperatives to be addressed when adopting rapid production technology. We conclude by arguing that all firms should adopt rapid production technology to avoid becoming at a disadvantage.

Keywords: Rapid, Prototyping, Production systems, Products, Printers, Manufacturing.

1. INTRODUCTION

Rapid production, and its different forms, has been moving steadily toward a mainstream manufacturing technique. It is a disruptive technology that has the potential to affect a range of industries. In addition, it has the ability to produce customized and personalized objects that were previously mere concepts. Hilton and Jacobs (2000) describe that the facets of production and process optimization involve the simulation of structural behaviours, material flow, and solidification. The industrial success associated with these areas depends on the ability to develop cutting edge technology with partners, so as to concurrently develop products and production processes which ensure that the benefits of reduced cycle times and raw materials can be achieved (Bullinger et al. 2000).

There has been ample research on rapid production in areas like materials and processes (cf. Norton 2001), but previous studies have not paid sufficient attention to increasing the understanding of what the aspects beyond manufacturing are that need to be addressed in order for companies to successfully adopt novel rapid production technology. For instance, Bogue (2013) points out that 3D printing technology is being used in a variety of applications, which basically fall into two broad categories: rapid prototyping and component manufacturing. However, we suggest that while rapid production is a transition in manufacturing technology, it consists of five consecutive evolutionary steps that should be understood to capitalize on the potential associated with rapid production technology. These steps, rapid prototyping, 3D printing, rapid tooling, rapid product development, and rapid manufacturing, are discussed in the following.

1.1 Step 1: Rapid prototyping

Rapid prototyping (RP) is a term used to describe the process of rapidly creating a system or part representation before final release or commercialization (Gibson et al. 2010). In product development, rapid prototyping refers to technologies which create physical prototypes from digital data simulations. Furthermore, it allows users to test prototypes of different versions of the models before full scale manufacturing.

Prototyping is an essential part of the product development and manufacturing cycle required for assessing the form, fit, and functionality of a design before a significant investment in tooling is made (Pham & Gault 1998). Rapid prototypes, i.e. goods derived from rapid prototyping, are mostly applied in design and development, product evaluation, production and process analysis, and manufacture tooling fabrication. The limited use may be due to a gap in the quality, strength, and volume of the goods produced using the currently available rapid prototyping technologies. However, rapid prototyping processes have already shortened turnaround times and lowered costs. These two factors bring about significant time and cost savings in product testing and development, enhancing the competitive advantage of a firm.

Rapid prototyping comprises several different processes that can be categorized into 10 main categories (Labgraph, 2014). Stereolithography (SLA) is notably the most popular rapid prototyping process, because it is perfect for fit and form

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testing or show models. Fused Deposition Modelling (FDM), which works on an additive principle by laying down material in layers, is commonly used for modelling, prototyping, and production applications. Inkjet Material Deposition (IDM) is an emerging technique in which inkjet technology is used to deposit materials on substrates. In Laminated Object Manufacturing (LOM), layers of adhesive-coated paper, plastic, or metal laminates are successively glued together and cut to shape with a knife or laser cutter.

Figure 1 depicts the evolutionary steps in rapid production, starting from rapid prototyping and advancing toward rapid manufacturing through the steps of 3D printing, rapid tooling, and rapid product development.

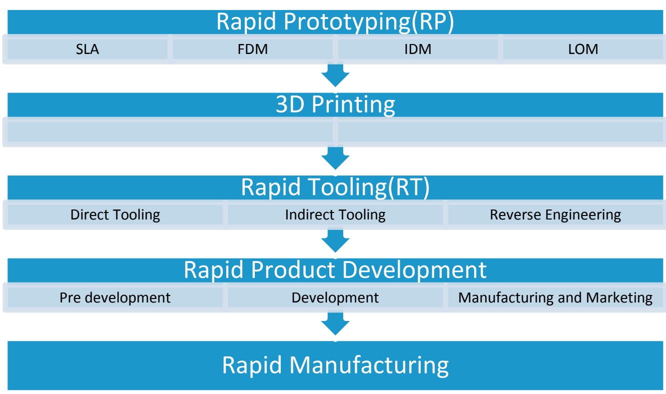

Fig. 1. Evolutionary steps of rapid production

1.2 Step 2: 3D Printing

3D printing employs an additive manufacturing process whereby products are built on a layer-by-layer-basis, through a series of cross sectional slices (Berman 2012). In contrast, current manufacturing processes use a subtractive approach that includes a combination of grinding, forging, bending, molding, cutting, welding, gluing, and assembling (CSC 2012). The use of 3D printing in a variety of sectors is rapidly gaining momentum; for example, it provides a fast and cost-efficient means of fabricating parts of machinery and instruments with customized design (Bogue 2013). 3D printing's rapid evolution can be attributed to mainly two features, which are i) control of how the ingredients are deposited and ii) its flexibility to manufacture different products, contrasting it to traditional manufacturing methods, in which the production line must be customized and tailored if the product line is changed, requiring expensive investment in tooling and long factory down-time (CSC 2012).

There are various machines that have enabled 3D printing. The main difference between them is related to how the layers are built up. Unlike a laser that draws a single line to convert material, 3D printers leverage their raster scan print head architecture to increase the amount of converted material (Bak 2003). Every next layer is added until the object is fully printed or 'manufactured' with an extruder (fused-filament), chemical agent (binder), or a laser (sintering/melting) changing the state of the material (Birtchnell & Urry 2013). In the manufacturing context, the technologies are particularly well suited to the production of components with complex geometries such as internal passageways, undercuts, and other features that are difficult or even impossible to manufacture with conventional techniques (Bogue 2013). Berman (2012) suggests there are two aspects that make 3D printing different from other rapid prototyping technologies: 1) it enables small quantities of customized goods to be produced at relatively low costs, and 2) it allows seamless integration with Computer Aided Designs (CAD) and other digital files like Magnetic Resonance Imaging (MRI). In addition, 3D printing changes the logistics chains by providing a platform for local production instead of large-scale and centralized manufacturing. This enables collaboration that is accelerating innovation and disruption in the material world, just as the Internet fostered collaboration, innovation, and disruption in the digital world (CSC 2012).

1.3 Step 3: Rapid tooling

Rapid tooling (RT) broadly describes any mold-making process that can create tools quickly and with minimum direct labour (Society of Manufacturing Engineers 2014). Rapid tooling is an application of rapid prototyping which is an automatic fabrication of machine tools. RT typically either uses a rapid prototyping model as a pattern or uses the rapid prototyping process directly to fabricate a tool for a limited volume of prototypes (FactoryOfFactories 2014).Tooling is a costly but necessary endeavour in manufacturing. Tooling costs can only be justified if the quantity is large and sufficient taking into perspective the economies of scale. RT has enhanced credibility to the rapid prototyping technologies by enabling the profitable reproduction of a limited number of tools. It is seen as a critical transitional stage moving rapid prototyping towards mainstream rapid manufacturing, and it consists of two categories: indirect tooling and direct tooling.

• Direct tooling

Direct tooling uses materials such as resins tools, metal powder, ceramic powder, microcast tools, and lamination tools, among others, in the rapid prototyping techniques. This process uses the CAD files and rapid prototyping processes to directly produce a tool as the final product.

• Indirect tooling

Indirect tooling uses a rapid prototyping model as a master pattern or case to make the molds by established routes (CERAM Research 2013). It can be separated into two diverse categories: soft tooling and hard tooling. Whereas hard tooling include spray metal tooling, electroformed tooling, castmetal tooling, and keltool tooling, soft tooling consists of silicone moulds and epoxy moulds.

Again, 3D printers can make rapid tooling a reality for companies of all sizes. According to Berman (2013) and FactoryOfFactories (2014), the advantages associated with the technology from the rapid tooling perspective include the separation of product design from manufacturing capabilities. From the business perspective, a key advantage is that it allows more effective sharing of design costs in a variety of business ecosystems compared to less information-intensive ways of production. Other advantages include shortened tool