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3D Printing - To print or not to print? Aspects to consider before adoption - A supply chain perspective

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Keywords

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3D Printing – To print or not to print? Aspects to consider before adoption – A supply chain perspective

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Abstract

3D printing is believed by many to be the next industrial revolution. The technology is already deployed in production. However, supply chain literature is still in its infancy regarding this topic, despite 3D printings radical impact on supply chains. A framework has been developed to assess various aspects that need to be considered when deploying such technology as part of the production process. Literature has been drawn from cross-discipline (e.g. social sciences, engineering, and business). The challenge for businesses will be whether to incur the cost impact today or the opportunity cost of tomorrow if 3D printing is not adopted.

Keywords: 3D Printing, Supply chain management, Innovation

Topics: Supply chain management, Innovation, Product and Service Development, and Next generation operations

Introduction / Purpose

3D printing can be defined as "the fabrication of products through the use of printers which either place layer upon layer…or employ lasers to burn materials" (Pannett, 2014, p. 34). The technology is over 20 years old, however it is believed by many that 3D printing will be coming in a large wave in the near future (Petrick and Simpson, 2013). Key patents are beginning to expire and 3D printing is projected to increase substantially over the next 5 years (PressWire, 2014; and Beaman, Bourell & Wallace, 2014). Business landscapes are changing, with great opportunities for new entrants, technological and business developments in the area of 3D printing. Countries such as America are preparing with programs including America Makes (Taylor, 2013) to create hubs of innovation across the US (Goulding, Bonafe & Savell, 2013), Singapore have planned to invest $500 million over a 5 year period (3ders, 2013a), the UK recently invested £14.7 million (3ders, 2013b), Australia is looking to invest $40 million over a seven year period (Phillips, 2014), New Zealand have invested $12.7 million (Kim & Robb, 2014), and many others are following suit. Education programs are also being established with a heavy focus in China (Krassenstein, 2015), Korea (Yeol, 2015) and the USA (Goulding, Bonafe & Savell, 2013).

Companies large and small are beginning to utilise this technology more, with Boeing 3D printing approximately 300 parts (Catalano, 2015), and Monash University and the CSIRO in Australia producing 3D printed jet engines (Science in Public, 2015). Access to such technology for hobbyists or "prosumers", consumers who produce (Petrick & Simpson, 2014, p. 14) is improving as it becomes more affordable (Beauman et al., 2014), and the capability of 3D printing continues to increase. Changes are coming, and industry and academia need to be ready. In a database search using Google Scholar, there were few articles concerning this technology and supply chain management, highlighting the need for more to be done in this area. The purpose of this paper is to explore the impact that 3D printing will have on the supply chain/ organisations, through an in-depth literature review. The research question being addressed is:

- What are the key aspects to be considered by supply chain managers prior to deploying 3D printing within manufacturing?

Key aspect categories being investigated include technical, social, managerial and environmental aspects which will be used for assessing the development of 3D printing capability. The paper starts with an overview of the current literature landscape, following by a methodology section. Core findings are presented and discussed in the later section of the paper.

Literature Review

What is 3D Printing?

3D printing began with the use of polymer and over the years other materials such as bio, metals, and even chocolate have been gaining momentum as the technology improves (Petrick & Simpson, 2013; Prince, 2014; Li et al., 2014). It has been described in many ways such as being revolutionary (Goulding, Bonafe and Savell, 2013), magical (Massis, 2013) and disruptive (Prince, 2014). 3D printing uses the combination

of creativity and software to produce "three-dimensional physical objects… based on a digital blueprint" (Gebler et al., 2014).

3D printing technology ranges from fused deposition modelling (Prince, 2014), developed in the 1980's, which involves layering plastic to create models, to selective laser sintering that uses powdered materials such as aluminium and titanium (Prince, 2014; Goulding, Bonafe and Savell, 2013). Polymers are most commonly used in 3D printing though there is potential to develop metallic use such as titanium further. According to RolandBerger (2013), the use of metal in 3D printing is increasing faster than the use of polymers.

The industries that 3D printing is currently trending are widespread and include but are not limited to; medicine, architecture, fashion, manufacturing, food and military (Petrick and Simpson, 2013; Ray, 2013 and Li et al., 2014). According to literature, it is particularly dominant in the medical field as it allows for the customisation of implants, hearing aids, medication (Vorndran, Moseke, and Gbureck, 2015; Goyanes, 2014), and tissue and bone engineering (Richards et al., 2013; and Bose et al., 2013). It is currently becoming more popular as the technology matures and awareness grows. Design programs and communities of 3D printing enthusiasts who share knowledge and use open source data, allow for designs to be shared and continuously improved upon. For example using 3D printing to produce a fully-functioning hand for a girl who was born without one. 3D printing not only has the ability to impact on how products are produced but also how organisations function.

What does 3D printing mean for the supply chain?

Supply chains can be defined as "a network of connected and interdependent organisations mutually and co-operatively working together to control, manage and improve the flow of materials and information from suppliers to end users" (Christopher, 2011, p4). Supply chain management focuses on more than just one aspect of the organisation, from raw materials to end users and suppliers, and can be viewed as consisting of multiple value streams. A value stream is made up of different processes or "special activities" (Womack and Jones, as cited by Childerhouse and Towill, 2004, p. 585). A pragmatic explanation is that a supply chain exists of multiple value streams. Value stream designs differ from industry to industry. Value stream designs also change over time as well, especially with the evolution of technology such as robotics, the internet, and 3D printing.

Supply chains are expected to become more flexible as 3D printing technology develops (Ray, 2013). The focus will shift towards raw materials (Pannett, 2014), localised production, consumer production or "prosumers" (Petrick and Simpson, 2014, p. 14), and design for example. According to Petrick & Simpson (2013, p. 12) unlike traditional mass manufacturing, there will be "two sets of rules: economies of scale for interchangeable parts produced at high volumes and economies of one for highly customizable products that can be built layer upon layer". Importantly, the changes won't rule out the supply chain, rather they will provide new challenges and opportunities and will require businesses to redefine their value streams to remain competitive.

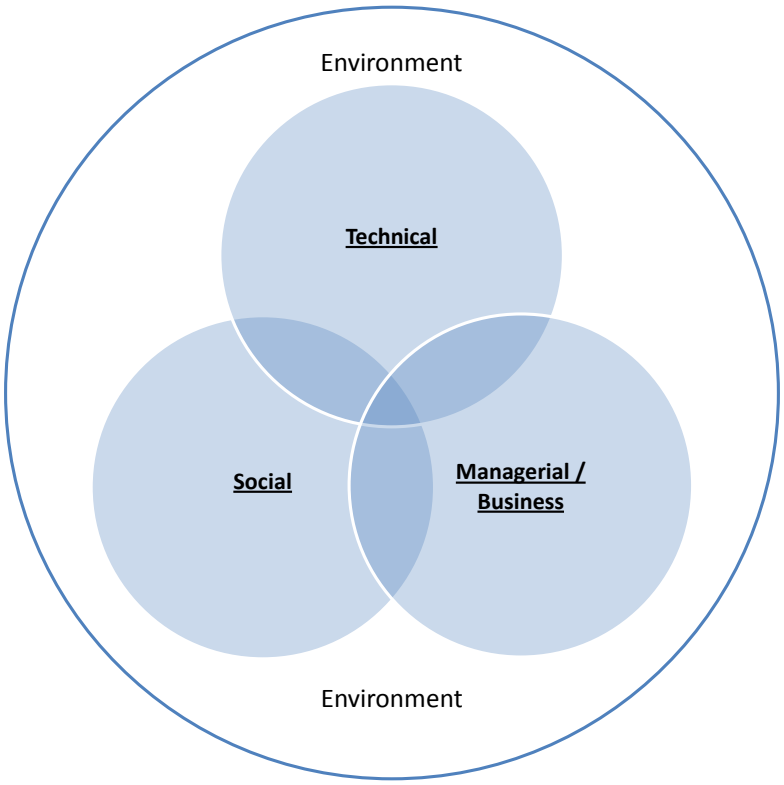
To print or not to print - Aspects to be considered

Focus needs to be given to more than just the technical aspects of 3D printing. Variables identified in the conceptual model for consideration include four main areas:

- Technical (e.g. capability, quality, technology, complexity).
- Managerial/Business (e.g. supply chain capability, power position shifts, lead time, logistics, customer demands, production location/hubs, manufacturing, raw materials, inventory, cost).
- Social (e.g. sustainability, environmental impact, consumer concerns/acceptance/ethics, education).
- Environmental (e.g. changing technology, and consumer demands).

Figure 1 shows the aspect categories to be considered. These were chosen due to their relevance to the area of 3D printing and the opportunity to increase awareness and collaboration across the disciplines. Supply chain managers among others in the organisation should look at these variables using a systems approach. The interaction and impact that the variables have on each other need to be considered, just as different departments or value streams interact within the organisation.

Figure 1 – Aspect categories



Source: (Authors)

The importance of each aspect will depend on factors such as the industry, supply chain maturity, available technology, materials being used and objectives of the organisation. Objectives can be viewed as being to improve existing value streams, such as; reducing costs/ inventory, improving transportability, part replacement, providing new solutions, and increasing flexibility, or to develop new value streams, including; entering new markets, increasing creativity, and creating new customer demand to remain competitive in the ever-changing world of business. Supply chain and operations

managers are faced with an interesting paradox. The aspects to be considered prior to be deploying 3D printers as part of production are complex and manifold; however the outcome will potentially lead to a simplified and streamlined material flow. The developed conceptual model has the potential to guide managers through that complex decision making process.

Design/methodology/approach:
This research is based on an in-depth literature review on the various aspects and facets of 3D printing. Literate from cross-disciplines such as social sciences, engineering and management have been drawn from a key word database search that was conducted using Google Scholar as per Table 1 below. The search was broad, and multiple words relating to 3D printing were used to investigate the impact that it would have on the number of articles that are available.

Table 1 – Database search results

Search words in title:	No. of results/articles:
3D printing	1,270
3D printing, supply chain	4
3D printing management	6
Additive Manufacturing	1,530
Additive Manufacturing, supply chain	10
Additive Manufacturing, management	12
Rapid Prototyping	6,420
Rapid Prototyping, supply chain	3
Rapid Prototyping, management	39

Source: (Authors)

There were substantially fewer articles when the key words supply chain or management were used. The results were dominated by the sciences (e.g. medical) and technical/engineering, highlighting the real need for further investigation in the supply chain / business area. In terms of what is being produced by 3D printing there were articles concerning spare parts (Khajavi, Partanen & Holmström, 2014), to bones / ceramic/dental implants (Fredorovich et al., 2011; and Wiria et al., 2010) and weapons (Walther, 2014) for example. Materials being used are also quite broad, from polymers (Hofmann, 2014), bio (Aggarwal & Khetrapal, 2014), ceramics (Irsen, et al. 2006), metal (Ribero, 1998), to cement (Gibbons, Williamans & Purnell, 2010) and chocolate (Lei et al, 2014) to name a few.

Article selection criteria was based on the title, abstract, and relevance to the area (for example the type of management being explored). Date range was not limited, and the search was kept broad regarding industry and materials being used in order to get an understanding of the landscape. In total 135 articles were reviewed and other literature and industry publications were reviewed in addition to this (to get an insight into current events and industry).

Findings
These findings demonstrate the capability of the technology and opportunity there is in this area for organisations and communities. There are many aspects to be considered, ranging from technical/engineering to social, managerial and environmental aspects. A

systems approach should be taken when assessing these, as the aspects impact on each other and should not be considered in isolation. They may also overlap in some categories. For example raw materials are important technically due to particle size, and chemical composition to ensure the integrity of the finished product for example, but also to business due to availability and weight for transportation and avoiding bottlenecks in production, and socially due to sustainability (Benatmane, 2010). A conceptual model has been developed to assess the major aspects to be considered by supply chain and operations managers prior to deploying this technology on the production line. The following tables summarise the aspects by category.

Is 3D printing feasible? Technical aspects to be considered vary from capability and technology to raw materials and design (as demonstrated in Table 2 below). The organisation needs to firstly decide whether adopting such technology is feasible, both in what is to be produced and the machines or suite of technology available. The product or part may require multi-materials and colours or complex unique designs with support structures. As well as this complexity, the raw materials chemical composition and reliability will be crucial to the integrity of the finished product. This leads to the question as to whether it is feasible to 3D print or use traditional manufacturing?

Table 2 – Technical Aspects

Variable/Aspect:	**Reference/ Source:**
Printing capability	RolandBerger, 2013
Quality outcome	RolandBerger, 2013
Technology (30+ types of machines/ printers and suites of technology available)	Ribero, 1998; RolandBerger, 2013; Petrick & Simpson, 2013; Vorndran Moseke & Gloreck, 2015; and Li et al., 2014
Product and process complexity (support requirements/ structures, geometry, moulds)	RolandBerger, 2013; Cohen, George & Shaw, 2015
Raw materials (e.g. chemical composition, particle size, new/recycled, sustainability)	RolandBerger, 2013
CAD design	Petrick & Simpson, 2013

Source: (Authors)

What cost implications or savings do managers have to understand before adopting such technology from a SC perspective? 3D printing has the potential to streamline supply chains, reduce inventory, assist in customisation of products, localise production, improve transportation costs and reduce the time to market for example. The operational strategy of the business and products that it produces needs to suit 3D printing and vice versa. The cost and suitability of adopting this technology needs to be assessed prior to implementation.

Table 3 – Managerial / Business Aspects

Variable/Aspect:	**Reference/ Source:**
Supply chain (SC) capability	Petrick & Simpson, 2013
Product/ Product lifecycle	Cohen, George & Shaw, 2015; Pannett, 2014; Petrick & Simpson, 2013
Raw material (e.g. type,	Benatmane, 2010

availability, weight)	
Inventory cost	Cohen, George & Shaw, 2015
Operational strategy (e.g. design to order, process simplification)	Cohen, George & Shaw, 2015; Petrick & Simpson, 2013; Pannett, 2014; Ratto & Ree; Barnes, 2014 Beaman, Bourell & Wallace, 2014
Marketing strategy / Customers wants/ needs	Ratto & Ree, 2012; Petrick & Simpson, 2013
Production location/ hub/ infrastructure	Birtchnell & Urry, 2012; Petrick & Simpson, 2013; Barnes, 2014; Ratto & Ree, 2012; Gress & Kalafsky, 2015
Logistics / Transportation cost	Benatmane, 2010; Birtchnell & Urry, 2013; Petrick & Simpson, 2013; Barnes, 2014
Lead time compression	Barnes, 2014
Patents/ IP/ Copyright	Phillips, 2015; Li et al., 2014; Pannett, 2014; Beauman, Borell & Wallace, 2014; Ratto & Ree, 2012
Power avoidance through insourcing	Böhme et al., 2008
Supply chain flexibility and design	Pannett, 2014; Petrick & Simpson, 2013; Ray, 2013; Barnes, 2014

Source: (Authors)

How do we envision our society in 10-15 years? 3D printing technology impacts the community in many ways, from sustainability of products, waste and energy reduction, to the potential to create further employment opportunities, and knowledge growth. Ethical concerns and acceptance may also impact on the use of such technology and also need to be considered. 3D printing has the ability to shape society, though to what extent?

Table 4 – Social Aspects

Variable/Aspect:	**Reference/ Source:**
Sustainability/Reduced environmental impact	Benatmane, 2010
Consumer/community concerns/ Acceptance/ Ethics	Ratto & Ree, 2012; MacIsaac, 2013; Walther, 2014
Community/Government Involvement	Beauman, Bourell & Wallace, 2014; Ratto & Ree, 2012
Education – transforming society	Birtchnell & Urry, 2012

Source: (Authors)

Is there a real threat of not adopting or engaging with this technology? It is constantly evolving, as are customer needs, demands and competitive pressures. 3D printing may or may not be suited to certain value streams though organisations need to be aware of their environment and opportunity costs.

Table 5 – Environmental Aspects

Variable/Aspect:	**Reference/ Source:**
Changing technology	Pei, 2014; Birtchnell & Urry, 2013; Ray, 2013; Petrick & Simpson, 2013; RolandBerger, 2013
Changing consumer demands and	Petrick & Simpson, 2013

abilities	
Enhancing existing technology	RolandBerger, 2013
Sustainability – ecological need	Benatmane, 2010
Competitive pressures	Birtchnell & Urry, 2012

Source: (Authors)

Discussion and Conclusion

There is much complexity around 3D printing, which brings about the need to essentially reengineer value streams. It is a collaborative attempt across the whole organisation and there are many aspects to be considered, stemming not only from a business and technical perspective but also social and environmental aspects that require consideration.

This paper provided an overview of what 3D printing is, examples of industries that it is currently deployed in, how it can influence supply chains and aspects for consideration before adoption. It highlighted the need for increased awareness and collaboration in the area and future challenges and opportunities.

However, how does a company prepare for such a change? How does it educate itself? How can the fire for 3D printing be sparked in industry? When is the right time to adopt 3D printing? What additional aspects are managers currently considering when facing the 3D adoption challenge? Are all aspects of equally important or can even some aspects be disregarded? How has 3D printing impacted on manufacturing and the wider supply chain today? How will 3D printing impact manufacturing and the wider supply chain in future? How well is Australia positioned when compared to their international counterparts in regards to 3D printing? How does 3D supply chain costing compare with traditional manufacturing supply chain costing? How mature does your supply chain need to be in order to deploy 3D technology meaningfully and harvest its benefits?

It is expected that this research will contribute to academia/ theory and practice. A conceptual model or framework incorporating major aspects to be considered for businesses before pursuing 3D printing has been developed that will need to be verified through case study/ field research in industry. It is further expected that businesses will benefit from the model through informed and improved decision making prior to deploying such cutting edge technology on their production line.

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