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A holistic decision framework for 3D printing investments in global supply chains

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Abstract

Three-dimensional printing (3DP), also known as additive manufacturing, is associated with potentially strong stimuli for revenues and cost savings. Nevertheless, the benefits of 3DP compared to conventional manufacturing methods or external sourcing require a holistic analysis for investment decision making. Until now, research has merely assessed case study-related potentials and specific aspects like production costs. Comprehensive information about value drivers in the overall supply chain is weak. Existing value-based supply chain management concepts are only of limited suitability. This paper develops a framework for investment decisions based on Economic Value Added (EVA), providing assessment of value drivers in global supply chains, including an empirical study with eight companies across different industries.

Keywords: 3D printing; additive manufacturing; additive layer manufacturing; additive fabrication; AM; total cost of ownership; TCO; value drivers; cost analysis; cost drivers; investment decision; economic value added; EVA; supply chain; value chain; sourcing; production; distribution.

1. Introduction

Fast moving markets require a rethinking of manufacturing methods. On the one hand, customers demand innovative, individually customized products at high quality and a competitive price. On the other hand, companies face the challenge of shorter lifecycles, resulting in less time for amortization of investments in machinery and tooling. Three-dimensional printing (3DP) provides a solution to the challenges above [1].

3DP, also known as additive manufacturing, has been characterized as disruptive technology, such as digital books and music downloads, allowing companies to profitably serve small market segments with customer-tailored products while operating with little or no finished goods inventory. 3DP enables small quantities of customized goods to be manufactured at relatively low costs by utilizing an additive manufacturing process whereby products are built on a layer-by-layer basis, through a series of cross-sectional slices based on digital 3D data [2].

Despite the increase in quality and significant price deterioration for 3DP technology, companies still primarily apply 3DP in the area of product development. A recent empirical study [3] revealed 73 percent use 3DP for testing of ideas and concepts, with

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67 percent using the printers for prototyping in research and development. Manufacturing of parts for the organization's use came in at 40 percent, which is more than twice as much as the manufacturing of production goods (19 percent), and nearly three times the manufacturing of customer supplies (14 percent). Process costs of 3DP are identified as one of the major barriers for a broader adoption as a manufacturing method [4]. Thus, the cost impacts of implementing 3DP need to be evaluated in detail.

This study contributes to the extending literature in 3DP by applying the approach of Economic Value Added (EVA) in order to ensure a holistic consideration of value drivers in global supply chains. The dynamic framework aims at supporting investment decisions in 3DP technology, considering not only manufacturing but overall supply chain costs. The research objective of this paper is to develop a framework for the systematic analysis of a potential investment in such a way that the decision on deploying 3DP technology generates value for the enterprise. The model presented is applicable for two investment scenarios: (1) 3DP versus conventional manufacturing methods and (2) 3DP versus external sourcing.

For this study, Action Research (AR) is employed; i.e., the researchers actively drive the identification process in constant feedback and interaction with eight companies in four industries: automotive, electronics, plastics, and food. AR has been widely accepted as quality research in many areas, including the supply management domain. The issue was resolved in collaborative work with the case companies, while expanding scientific knowledge by developing a 3DP specific investment framework based on EVA.

The research topic can be summarized as follows: how to effectively and efficiently support decisions regarding investments in 3DP by utilizing a cause-effect model, considering supply chain value drivers in source, make, deliver, and return. The topic will be tackled with the methodology developed in the following sections.

2. Research background

According to the research objective stated above, an overview of the relevant state of the art is provided in the coming sections. First, a closer look is taken at 3DP technology and associated economic aspects. Second, since investing in 3DP has to generate value for the enterprise, approaches of value-based management and their adoption to supply chain management have to be investigated. Third, the current state of research in the area of value impacts of 3DP has to be identified to sharpen the research agenda by means of an extensive literature review.

2.1. 3D printing technology and economic aspects

3DP is a technology that stems from stereolithography, being developed for Rapid Prototyping in the early eighties [5]. Nowadays, there is a broad variety of 3DP technologies and materials available [6]. Common elements of 3DP technologies are the use of 3D product data and the additive manufacturing method 'layer by layer' (as opposed to subtractive manufacturing like milling or drilling). While Rapid Prototyping focuses on prototypes to analyze product parameters in the product development phase, 3DP provides components for final products or the sellable product itself. Geometric freedom when designing a product is a striking advantage of 3DP compared to the constraints of conventional manufacturing methods: nearly all shapes can be realized [5]. Unlike conventional manufacturing methods, there is no direct relationship between product complexity and manufacturing costs: the complexity of the product design does not drive complexity for tooling or assembly labor [7]. Even requirements of free-moving parts (e.g. ball and socket joint) can be met by printing a single monolithic structure that does not have to be assembled [2]. The decrease in the number of parts as well as fewer assembly steps result in a significant reduction of production costs as compared to conventional manufacturing methods. Integrating an assembly into a single part can also result in fewer subcontractors in the supply chain and thus reduced coordination costs [1].

3DP allows companies to profitably serve small market segments with customer-tailored products as it does not require costly tooling, resulting in fixed costs. Thus, also the introduction of new products is less risky [7]. With 3DP on demand, there are no capital charges and scrapping risks due to unsold finished goods inventories [2]. Instead, firms only hold digital 3D data in stock. Hence, 3DP is especially suitable for product portfolios characterized by a high mix of variants and a low volume per variant.

Major advantages of 3DP, compared to injection molding or machining (subtractive manufacturing), relate to cost effectiveness and speed. Contrary to injection molding, 3DP entails relatively low fixed costs as it does not require expensive tooling or molds [7]. Thus, it is particularly cost effective for very small production lot sizes, enabling firms to profitably serve niche markets and fulfill highly tailored customer requests. In comparison to subtractive manufacturing methods, carving materials to the desired shape by machining such as milling and drilling, there is less waste material [2]. Petrovic et al. [8] report waste reductions for metal applications by 40% in comparison to machining. Moreover, over 95% of waste material can be re-utilized for 3DP. Contrary to injection molding and subtractive manufacturing methods, the costs per part do not decrease with the size of the production lot due to little or no change-over time [2]. Moreover, 3DP helps to shorten the time-to-market, utilizing rapid prototyping [9]. With regards to attractiveness and fields of application for serial production, especially the aircraft industry [10], the automotive industry, and