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Critical success factors for adoption of 3D printing

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ABSTRACT

Although 3D printing is a collection of digital manufacturing technologies, the speed of its adoption has not been quite what the market has expected. The purpose of this research is to examine the organizational perspectives and factors that are influencing the adoption of 3D printing. This paper presents a hybrid approach to the integrated analytic hierarchy process (AHP) and the technology-organizational-environment (TOE) framework, in order to set up a proper evaluation model that can prioritize the impact of such factors. A*n empirical study* has been carried out on Taiwanese manufacturing enterprises, a considerable amount of information has been revealed that can help manufacturers understand those key factors better. Finally, the results herein provide decision-makers a way to discover more effective strategies to adopt 3D printing.

1. Introduction

While the presence of 3D printing is fully subversive to the traditional technologies of design and manufacturing, it has also produced profound influences on many aspects, like economics, geopolitics, sociology, environment, demography, and security (Matias and Rao, 2015; Jiang et al., 2017; Xu et al., 2017). 3D printing can be described as a collection of digital manufacturing technologies, producing layer-by-layer components through a full utilization of materials (West and Kuk, 2016; Sandström, 2016; Kwak et al., 2017). Compared with traditional technologies, 3D printing offers many advantages, like fast fabrication, high precision, and product customization.

The potential of 3D printing actually lies in the fact that it largely reduces the time interval between equipment changes on a large-scale production line and allows for frequent innovations on an item during the manufacturing process; at the same time, the degree of customization of the resulting mass production is much higher (Hasiuk, 2014; Rayna and Striukova, 2016; Kapetaniou et al., 2018). The economic benefits from this technology include the further promotion and development of manufacturing, retailing, health care, and other aspects (Jia et al., 2016). A recent survey conducted by Allied Market Research (AMR) suggests that the global 3D printing market was valued at US $2.3 billion in 2013, growing to US$8.6 billion by 2020 at an annual rate (CAGR) of 20.6%.

Despite the fact that 3D printing has brought forth many advantages for organizations, it has not been widely used. For example, related studies show that the percentage of 3D printing in the manufacturing market is still less than 2% (Wohlers and Gornet, 2014). Moreover, many factory firms are still struggled to incorporate this promising technology into their production lines and products' optimization. Overall, it seems that the adoption of 3D printing has turned into a big challenge for businesses.

Considering the low adoption rate, it is important to figure out the main reasons behind this. On one hand, the cost of 3D printing is based on both printing speed and printing materials. To date, its applications have been limited to several aspects, such as making prototypes or customizing items for industry; in fact, the important economic factor is that the cost of 3D printing is higher than that of traditional manufacturing (Despeisse et al., 2017). Under such concern, firms doubt whether or not 3D printing is worth going into production, compared to other technologies. If they cannot make higher profits from 3D printing, then they will not adopt it.

The technology-organization-environment (TOE) framework has been widely utilized to explain how to adopt technological innovation from the perspective of an organization (Tornatzky and Fleischer, 1990; Wu and Chen, 2014). This framework identifies three factors that directly influence an organization's implementation of technological innovations: technological context, organizational context, and environmental context. Although previous studies have identified important factors that can promote the adoption of technological innovation, these factors do not play important roles with respect to 3D printing. Moreover, the previous studies mainly adopted structural equation modeling (SEM) to construct and verify the TOE model. However, the new technology is highly complicated, not all respondents have thorough comprehension. Certain variables are not compatible with assumption of independence, and causal relationship cannot be analyzed

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accurately if mass samplings are difficult to obtain, resulting in mistaken conclusions.

This study builds up a more comprehensive framework that incorporates cost factors from the perspective of manufacturing, with the goal of answering the following question: What are the key factors that affect the adoption of 3D printing from the perspective of organizations? To find reasonable answers to this question, the present study's contribution to the literature covers three aspects. First, the adoption of 3D printing and the coordination of production, marketing, and research and development (R&D) are difficult due to various reasons. From a comparison of different organizational actors, we provide a valuable reference of the organizational characteristics influencing the adoption of 3D printing. Second, by evaluating the relative importance of various issues in its adoption, this study presents contingency factors that could potentially affect 3D printing. Finally, whereas previous studies on 3D printing adoption do not offer a basic theory to support their research, our study empirically examines the determinants of 3D printing adoption based on the TOE framework, which is applied by many studies involving adoptions of different innovations.

The use of 3D printing is actually a multiple criteria decision-making (MCDM) issue. Among the many MCDM approaches, the analytic hierarchy process (AHP) is the most often used one (Saaty, 1981, 1989, 1990). Under any given situation, preferences can be specified by a decision maker via natural language expressions regarding the significance of each evaluation item (Kwong and Bai, 2002). Human judgment about preferences are always very imprecise and subjective, thus fuzzy concept is necessary for handling problems characterized by vagueness and imprecision (Kahraman et al., 2003; Fu et al., 2006). Hence, there is a need to extend the AHP technique with fuzzy concept for making better decisions in fuzzy environments. To improve the above-mentioned drawbacks, this research adopts the fuzzy AHP method to determine those factors related to 3D printing adoption, using Taiwan's manufacturing industry as an example to show the feasibility of the proposed approach.

This paper is organized as follows. Section 2 presents the literature review of previous studies regarding 3D printing, summarizing all factors that might influence 3D printing technology. Section 3 discusses the critical related factors through the AHP approach. Section 4 presents the empirical results and managerial implications. Finally, Section 5 expresses the conclusions and expectations for further study.

2. Literature review

2.1. 3D printing

Additive manufacturing (AM), including 3D printing, is a newly created production process (Petrick and Simpson, 2013; Ford, 2014; Rayna and Striukova, 2016). 3D printing is a collection of digital manufacturing technologies that produce layer-by-layer components via the full utilization of materials and is adopted based on computer-generated designs. A digital model can be reproduced via the consolidation of materials with an energy source (Berman, 2012; Pearce et al., 2010); this process employs a laser, a binder or an electron beam to solidify the material, since it is scanned over the pre-placed layer or is directed along the building path. Applications of this method have been very successful on polymers, metals, and ceramics.

Based on current research reports, academia has come to realize the significant contributions that 3D printing has brought to traditional manufacturing. From a qualitative case study analysis, Mellor et al. (2014) established an approach for implementing factors related to elements from AM technology. The literature revealed the influence that AM technology has in both economic and technological fields is also revealed. Thomas (2015) put forth three fundamental aspects on the economic functions of AM: an assessment on the value of produced goods; an evaluation on the costs and profits from implementing the technology; and an estimation on the conditions for implementing and spreading the technology.

Some related research studies have concentrated on the comprehensive design of the technology, while others looked at its economic influence as delivered through its adoption and diffusion. In comparison, our research aims at both explaining the decision of 3D technology implementation and introducing rules for such a decision. In addition, because a lot of previous research on 3D printing implementation is not based on solid facts or convincing theory, our research focuses on examining the determinants of its actual implementation under the TOE framework.

2.2. Factors influencing 3D printing implementation

Research on this abovementioned field is just in its infancy. The exploratory research of Mellor et al. (2014) on factors influencing AM technology implementation revealed the following influences: external force, technological factors, organizational factors, strategic factors, operational factors, and supply chain. Muita et al. (2015) noted that the implementation of quick manufacturing is affected by business issues like business models, industry features, and goods or service transitions, while other research regarded logistics as the least impacted area of this type of manufacturing. Attaran (2016) pointed out the main obstacles for 3D printing implementation: technology, cost, and material. The size of produced goods, government regulations, and restrictions on cost also affect 3D printing implementation.

On the basis of the technology acceptance model, Wang et al. (2016) explained that both direct factors and influential effects influence 3D printing implementation for Chinese customers. In light of related research, 3D printing implementation is inclined to be affected by the external environment where the business firms reside. In addition, other research studies have concentrated on another particular factor – namely technology itself. Thus, more research should be devoted to the introduction and analysis of business-related factors for the issue of 3D printing implementation.

Previous research also identified the technology-organization-environment (TOE) framework as a powerful tool for analyzing the elementary factors when employing new technology in a given organization. Under this framework, researchers are inclined to choose various organizational, technological, and environmental factors for various technologies, so that the TOE framework can be adopted in broader conditions (Baker, 2012). On basis of TOE framework, this research establishes and analyzes an implementation model for 3D printing.

Apart from the TOE framework, like in the case of other technologies, costs play another crucial function in 3D printing implementation (Kreiger et al., 2014; Brooks et al., 2014; Weller et al., 2015). More specifically, various types of costs for things like hardware or materials are incorporated in the whole cost of 3D printing implementation. Moreover, through the approach of cost-benefit analysis, Thomas (2015) examined and explained societal investments and profits from 3D printing implementation, while Weller et al. (2015) pointed out the economic and technological factors of manufacturing firms during the process of AM implementation. In this case, several factors associated with the costs of 3D printing implementation need to be taken into consideration before widespread application of the technology takes place. In light of the existing literature, through a combination of the TOE framework and the cost factors - both of which are composed of a four-dimensional framework (technology, organization, environment, and cost) this research aims at assessing 3D printing implementation by manufacturing firms. We next introduce the multi-dimensional factors.

2.2.1. Technological dimension

Technological dimension delivers internal and external effects of a technology's application in organizations. Bharadwaj (2000) revealed that information technology, functioning as a type of resource, only enhances competitiveness when it combines with or improves pre-existing resources or techniques. Therefore, in the process of technology implementation, technology infrastructure plays a fundamental role and also influences the eventual usage of 3D technology. 3D printers are