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. An 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; Kapetanioy 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 struggling 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.
accurately if mass samplings are difficult to obtain, resulting in mis-
taken conclusions.

This study builds up a more comprehensive framework that in-
corporates 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 organiza-
tions? 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 re-
search 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 ana-
lytic 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 sig-
nificance 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 (Kahrman 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 dis-

cusses the critical related factors through the AHP approach. Section 4 pre-
sents 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 con-
solidation 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 man-
ufacturing. 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 re-
search, 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-en-
vironment (TOE) framework as a powerful tool for analyzing the ele-
mentary factors when employing new technology in a given organiza-
tion. 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 technolo-
gies, 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. Bhaskarwad (2000) revealed
that information technology, functioning as a type of resource, only
enhances competitiveness when it combines with or improves pre-ex-
isting 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
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