Technology Assessment of 3D Printing Using a Two-Stage MCDM: Case Studies on Molding Industry

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Abstract

In the current product development process, it can be divided into three stages: product design, verification testing, and mass production. In the design and verification stages, design changes caused by product design differences or other factors often occur, thereby increasing the cost of mold production. If the development time and cost at this stage can be reduced, it will greatly help the timeliness and cost competitiveness of the product. Due to the investment scale, technical complexity, and competitive strategy of the mold manufacturer's introduction of 3D printing technology, its evaluation factors can be regarded as a multi-attribute decision-making process. Therefore, the purpose of this research is to provide a systematic approach to the decision-making evaluation of technology introduction, in which a two-stage procedure is proposed. In the first stage, the initial criteria are established through expert interviews and literature collection, and expert opinions are obtained through the fuzzy Delphi method to introduce important criteria for manufacturers to introduce new technologies. In the second stage, the Analytic Network Process method is used to evaluate the various dimensions of the expert evaluation and screening criteria as the measurement indicators, to find the importance of each criterion, and to establish an evaluation model to provide reference for decision makers.

Keywords: Technical assessment, three-dimensional printing, fuzzy Delphi method, fuzzy hierarchical analysis method

1. Introduction

Many study on manufacturing and technology management show that companies have invested a lot of money in advanced manufacturing technology and new management models to respond to the rapidly changing production process and the needs from clients, learn new production technology and correct understanding and implementation. Help companies improve their competitiveness under the control of cost, quality, flexibility, delivery speed, production efficiency and profitability (Elitan, 2007). Therefore, the key to the decision-making involved in the selection and evaluation of new technologies lies in whether it can bring effective benefits and value creation for enterprises in a competitive situation, and choose a new production technology that combines market trends, competition and business strategies. And the business strategy of manufacturing attributes are all important factors in decision-making evaluation (Chuang, 2009). With the continuous innovation of new technologies, manufacturers should evaluate the introduction of new technologies on the premise that new external technologies can improve process capabilities and create commercial advantages. Among them, manufacturers may think about not only internal financial resources, but also considering external factors, corporate planning and performance, etc. (Betz, 2011; Chen & Small, 1994; Cho & Yu, 2000).

This study uses the fuzzy Delphi method to explore the important factors for the evaluation and consideration of manufacturers for the introduction of new technologies, and calculates the importance of each element by means of fuzzy hierarchical analysis. This model has the characteristics of determining priorities, generating alternatives and choosing the best solution, and provides decision-makers as a reference for selection evaluation, objective and standardized decision-making. The purpose of this research is to explore the evaluation and decision-making models of manufacturers when introducing new technologies, and take Taiwan mold manufacturers to introduce 3D printing technology as an example.

The production of molds can be divided into direct modeling and indirect modeling (Rosochowski & Matuszak, 2000). The direct modeling method means that the processed shape is the mold during rapid prototyping, and the indirect modeling the rule is that in the RP stage, its appearance is the product we want, and then it is remade to get the mold. The traditional molding method of the model enters the mold development stage after object design and drawing. According to the different molding technology, it can be divided into fluid liquid molding material, solid molding, composite and powder material, etc. Finally, the mold modification or Remake. In industrial manufacturing, after final confirmation of the model samples, the molds used in mass production will be made. The mold industry is different from other industrial products. For example, mold products belong to a highly customized industry. If the demand is limited, customers usually only develop special molds based on the characteristics of the samples, instead of mass customization and mass production. In addition, the mold manufacturing process requires the use of a large amount of professional knowledge and experience. Because of the molds made for specific products, the characteristics of each mold are different. From the selection of forming processing materials and materials to the design and setting of the part mechanism, it is often it determines the quality, cost and delivery time of mold production. Therefore, in order to respond to market competition, it is necessary to achieve an effective and rapid product development process that responds to customer needs (Kochan et al., 1999).

Three-dimensional printing refers to a manufacturing process technology, a type of rapid prototyping technology. It is based on digital model files, using powdered metal or plastic and other bondable materials to construct objects through layer-by-layer printing, so that the model industry can be customized, fast and fast through 3D printing. Flexible and other advantages, it shortens the process in mold design and manufacturing, such as: direct printing of samples for trial, synchronization of design and manufacturing, and shortening of development processes. 3D printing is an emerging technology that is rapidly developing in the manufacturing industry. It generates objects of any shape by adding materials, which can effectively shorten the product development cycle, improve product quality and reduce production costs.

2. Literature Review

2.1 Technical Evaluation Related Literature

The decision of technology selection and evaluation will involve the profit growth and competitiveness of the enterprise, and the process of evaluating technology requires the support and resources from the enterprise to analyze, including tangible and intangible assets (Chan et al., 2000). Mohonty and Deshmukh (1998) believe that it is necessary to consider the internal and external strategies and financial factors of the enterprise when investing in advanced manufacturing technology. This research focuses on the review and collation of related literature on past technology evaluation and selection as shown in Table 1. Lee and Chou (2016) used a hierarchical analysis method to evaluate three-dimensional integrated circuit technology options, using 14 criteria as the basis for technical evaluation. Pun et al. (2017) used hierarchical analysis to evaluate the proposed system in the maintenance and management of building facilities to formulate appropriate strategies to improve efficiency and reduce costs. Awasthi et al. (2018) proposed a global supplier selection based on Fuzzy AHP-VIKOR for sustainability standards. Hamdia et al. (2018) the importance of using modular hierarchy analysis to evaluate the standards of building structures. Armando Calabrese et al. (2019) this paper proposes a method of applying Fuzzy AHP to select those sustainability issues that are most relevant to create shared value for enterprises and society, and should be the focus of strategic planning and management. The main purpose of the research of Khan et al. (2019) is to use the Fuzzy AHP method to develop a classification method for SPI success factors, and to prioritize them appropriately, thereby helping to eliminate ambiguity and uncertainty. Chatterjee and Stević (2019) use Fuzzy AHP-TOPSIS for supplier selection and evaluation. Si et al. (2020) used the Fuzzy AHP method to construct a multi-standard comprehensive efficiency evaluation including technical, environmental protection, economic and social benefits, and demonstrated the decision-making evaluation process for coal-fired unit processing technology in a case. Taylan et al. (2020) used the Fuzzy AHP-VIKOR-TOPSIS method to evaluate the most suitable energy system for investment. Hemmati et al. (2018) use the FANP model to select the best maintenance strategy plants for different equipment for acid production. Agrawal et al. (2020) selected three main attributes and 15 sub-attributes located at level 1 and level 2, as well as 10 different software alternatives of the institute.

Table 1: Evaluation Criteria Related Literature

Research method	Researcher	Criteria
Fuzzy AHP	Lee and Chou (2016)	14
Fuzzy AHP	Pun et al. (2017)	5
Fuzzy AHP-VIKOR	Awasthi, Govindan, and Gold (2018)	11
Fuzzy AHP	Hamdia, Arafa, and Alqedra (2018)	17
Fuzzy AHP	Calabrese et al. (2019)	36
Fuzzy AHP	Khan et al. (2019)	21
Fuzzy AHP-TOPSIS	Chatterjee and Stević (2019)	9
Fuzzy AHP	Si et al. (2020)	15
Fuzzy AHP-VIKOR-TOPSIS	Taylan et al. (2020)	30
Fuzzy ANP	Hemmati et al. (2018)	7
Fuzzy ANP-TOPSIS	Agrawal et al. (2020)	35

Analytic Hierarchy Process (AHP) is a multi-objective decision-making method. A set of decision-making methods developed by Saaty in 1971 is mainly used in uncertain situations and decision-making problems with multiple evaluation criteria (Saaty, 1980), due to the advantages of AHP's simple theory and expressive program sequence, and it has been widely used. Analytic Network Process (ANP) was proposed by Saaty in 1996. It is an extension of the analytical hierarchy process method. The ANP method mainly adds dependencies and feedback effects, including the interaction and feedback effects between clusters and clusters. Using supermatrix to calculate the degree of influence of interdependence makes ANP closer to the human thinking mode.

Because people's thinking patterns and cognition of things often have varying degrees of ambiguity, the semantic scale of the traditional AHP method cannot cover the fuzzy uncertainty of decision-makers in problem decision-making, so follow-up researchers use fuzzy theory and fuzzy to solve the problem of fuzzy, triangular fuzzy numbers are used in the matrix of pairwise comparison, and the Fuzzy Analytic Hierarchy Process is developed (Buckley, 1985). The fuzzy hierarchical analysis method is the combined application of the hierarchical analysis method and the fuzzy theory. Based on the inaccuracy of the traditional AHP method and the method used to obtain the weight, it is difficult to be used in the calculation of the fuzzy matrix. Therefore, this method was developed. Transform the concept of consistency into a fuzzy matrix (Hsu & Chen, 1996).

Zwick et al. (1987) proposed that fuzzy number similarity is formed by expert consensus in group decision-making, and is generated by group decision-making. In traditional decision-making models, arithmetic average or geometric average is often used as integrated experts the method of calculation when evaluating opinions, but there are often doubts about the results. Hsu and Chen (1996) proposed the Similarity Aggregation Method, which uses the concept of fuzzy number intersection to calculate and integrate the decision-making opinions of experts. SAM uses similarity functions to measure the agreement degree between two different experts to construct the concept of agreement matrix. To express the degree of agreement of the experts with each other's evaluation values, and consider the important degree and relative agreement degree of all experts for all evaluation values, define the consensus degree coefficient of the experts, and finally use the consensus degree coefficient of all experts as the weight, The weighted calculation is the fuzzy evaluation value integrated by the consensus of all experts.

3. Methodology

This research uses the concept of fuzzy theory, using "Delphi method" and “Analytic Network Process " as research and analysis methods, and the "similarity integration method" is used to integrate expert opinions to analyze the introduction of 3D columns by Taiwan mold manufacturer's Key factors for the evaluation of printing technology. In the first phase of this research, the fuzzy Delphi expert questionnaire was first issued, and various important aspects and evaluation factors were established through the opinions of industry expert decision-making groups. In the second stage, the Analytic Network Process method expert questionnaire is carried out to calculate the weight relationship between each dimension and the measurement index.

3.1 Initial Hierarchy

Based on the aforementioned related literature discussion and expert interviews, this study draws up a preliminary framework for Taiwan mold manufacturers to introduce a new technology evaluation model, which serves as the basis for the design of the fuzzy Delphi questionnaire and the selection basis for evaluation criteria to facilitate subsequent research. In the framework, the final goal is "Taiwan mold manufacturer's factor evaluation for the introduction of 3D printing technology". The initial hierarchical structure is divided into 5 dimensions and 32 evaluation items as shown in Table 2. The definition of individual criteria is shown in Table 3.

Table 2: Initial Evaluation Criteria

Criteria	Sub-Criteria
External environment	Technology trend, supply chain, competitive advantage in the industry, market technology demand, environmental impact, policy orientation
Internal resources	Purchase and construction equipment cost, inspection and control cost, labor cost, increase or decrease cost of raw material consumption, consumables cost, equipment maintenance cost, training and technology update cost
Business strategy	Financial strategy, marketing strategy, organizational ability, diversification strategy, R&D strategy, technical strategy, customer satisfaction
Technical planning	New technology risk, technical compatibility, reliability, capacity utilization, validity, information management system, flexibility
Operational performance	Quality achievement, system output, working environment, productivity efficiency, manpower requirements and training

Table 3: Criteria definition

Criteria	Definition
External environment	The definition of external environment is the general term for the business environment, competitive environment, and technological environment, economic and political environment faced by enterprises.
Internal resources	The definition of internal resources refers to the human, financial, tangible and intangible resources within the enterprise.
Business strategy	The definition of business strategy is the response taken by an enterprise in a competitive environment, considering its own strengths and weaknesses, in order to form advantages and create space for survival and development.
Technical planning	The definition of technical planning is a method used to derive and present business vision, provide technical management and overall planning.
Operational performance	The definition of job performance refers to the process improvement that can be effectively measured by new technology or technology.
A1.Technology trends	The future application trend of new technology in the market.
A2.Competitive advantage in the industry	The competitive situation in the industry using this technology.
A3.Market technology demand	It comes from the market's demand for new technologies.
B1.Purchase and construction equipment cost	The cost of construction and equipment (including software and hardware) required for technology.
B2.Inspection and control cost	The cost of disposing of inventory (including raw materials, semi-finished products, and finished products).
B3.Increase or decrease cost of raw material consumption	The cost of raw materials consumed in the production process.
B4.Consumables cost	Consumables (tangible and intangible) required for the operation of the system, such as consumables and electricity required for equipment.
B5.Equipment maintenance cost	The cost of regular maintenance and repair of high-tech equipment.
C1. Financial strategy	Whether the financial situation of the enterprise can pay for the investment plan for technology introduction, and whether this investment is in line with the overall strategy of the enterprise.
C2. R & D strategy	The degree of correlation between the R&D activities invested by the company and the introduction of technology.
C3. Technology Strategy	The indicators that evaluate the modernization, integration, and innovation of corporate strategies (for example, new manufacturing processes) also guide whether the technology will promote the implementation of these strategies.
C4. Customer satisfaction	The introduction of technology affects the extent of the gap between customers' expectations of products or services and the actual situation.
D1. New technology validity	Assess whether the technology can operate immediately and whether there is sufficient vendor support.
D2. Technical compatibility	The compatibility of the imported technology with the current system, including software and hardware.
D3. Technical reliability	The frequency of technical equipment failures, maintenance time, and the extent to which other systems are affected.
D4. Flexibility	Including quantity flexibility, design flexibility, program flexibility, operational flexibility, etc. This is to evaluate whether the imported technology can handle various changes.
D5. New technology risk	Various risks caused by the introduction of new technologies.
E1. System output	Evaluate the number of tasks that the system can complete in a unit of time.
E2. Operation environment	Whether the introduction of technology can provide a safer working environment and a more user-friendly human-machine interface.
E3. Productivity efficiency	An indicator for evaluating production efficiency.

The first stage is the fuzzy Delphi expert consultation, based on the preliminary hierarchy established above, mainly to assess the appropriateness and importance of various measurement aspects and evaluation indicators. The second stage is the expert questionnaire of fuzzy hierarchical analysis, which uses the statistical analysis results of the first stage of questionnaire survey to screen out the key evaluation factors that provide expert consensus, and establish the second stage hierarchical structure. The content of the questionnaire is mainly divided into two parts: the ranking of the importance of the evaluation criteria and the relative importance of the evaluation criteria. Using 1 to 9 evaluation scales, and then using the pairwise comparison method, let the experts fill in the questionnaire. The expert consultation of this research is aimed at a total of 14 experts in the field of industry such as mold manufacturers and professional management, the background of the experts is shown in Figure 1.

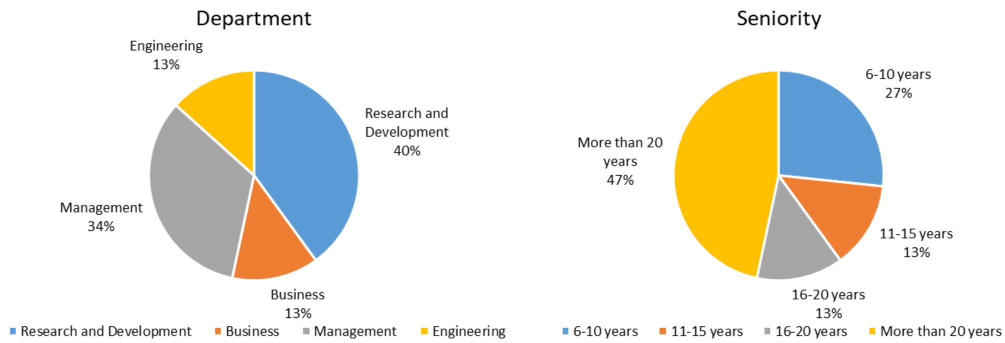

Figure 1: Expert's Work Department and Seniority

3.2 Data Analysis Method

3.2.1 Fuzzy Delphi method to select important evaluation criteria

In the first stage of the fuzzy Delphi method, this research uses the "double-triangular fuzzy number method" to integrate the opinions of experts. The steps are as follows:

Step 1: Each expert gives a possible interval value for each evaluation item.

Step 2: Analyze the "most conservative cognition value" and "most optimistic cognition value" of each evaluation item given by all experts. After removing the extreme values that fall outside 2 times the standard deviation, find the unremoved " The minimum, geometric mean, and maximum of the most conservative cognitive value, and the minimum, geometric mean, and maximum of the "most optimistic cognitive value".

Step 3: Through the above steps, the triangular fuzzy number of the "most conservative cognitive value" and the triangular fuzzy number of the "most optimistic cognitive value" can be established for each evaluation item.

Step 4: Check the degree of expert consensus.

3.2.2 Similarity calculation of expert fuzzy evaluation value

Integrate the weights of the experts on the evaluation criteria, and the expert evaluation opinions are converted into triangular fuzzy semantics (Zadeh, 1965) as shown in Table 4. The integration calculation steps are as follows:

Step 1: Calculate the degree of agreement between any two different experts.

Step 2: Build an agreement matrix.

Step 3: Calculate the average degree of agreement between each expert and other experts.

Step 4: Calculate the relative agreement degree of each expert.

Step 5: Calculate the consensus degree coefficient of each expert.

Step 6: Calculate the integration of the consensus degree coefficient of the experts and the fuzzy evaluation value.

Table 4: Symmetric Triangular Fuzzy Number

Fuzzy number	Semantic
$\tilde{1} = (1,1,2)$	Equally important
$\tilde{2} = (1,2,3)$	Somewhere between equally important and slightly important
$\tilde{3} = (2,3,4)$	Slightly important
$\tilde{4} = (3,4,5)$	Between slightly important and quite important
$\tilde{5} = (4,5,6)$	Quite important
$\tilde{6} = (5,6,7)$	Somewhere between very important and extremely important
$\tilde{7} = (6,7,8)$	Extremely important
$\tilde{8} = (7,8,9)$	Between extremely important and absolutely important
$\tilde{9} = (8,9,9)$	Absolutely important

3.2.3 Fuzzy Analytic Network Process method weight calculation

The steps of ANP are mainly divided into different stages such as forming a framework and problems, establishing a pairing comparison matrix and calculating its eigenvectors, verifying consistency, forming a supermatrix, and selecting the best plan. The steps of the ANP method in this study are as follows:

Step 1: Build a pairwise comparison matrix.

Step 2: Calculate eigenvalues and eigenvectors.

Step 3: Calculate the consistent surname test.

Step 4: Supermatrix calculation.

Step 5: Weight calculation.

Step 6: Sort.

4. Result

4.1 Adopted Assessment Criteria

Based on the literature review and the results of expert interviews, this research preliminarily draws up the principled evaluation factors for the consideration of "Taiwan mold manufacturers' evaluation model for 3D printing technology", and conducts an expert questionnaire survey of fuzzy Delphi method. At this stage, questionnaire surveys and interviews are conducted for experts in professional fields from Taiwan mold manufacturers. After the expert questionnaire was collected, Fuzzy Delphi was used for analysis. After the threshold value of the expert consensus was screened, the result contained 5 dimensions and 20 criteria as shown in Table 4. The second-stage hierarchical analysis framework established by the first-stage evaluation criteria screening is shown in Figure 2.

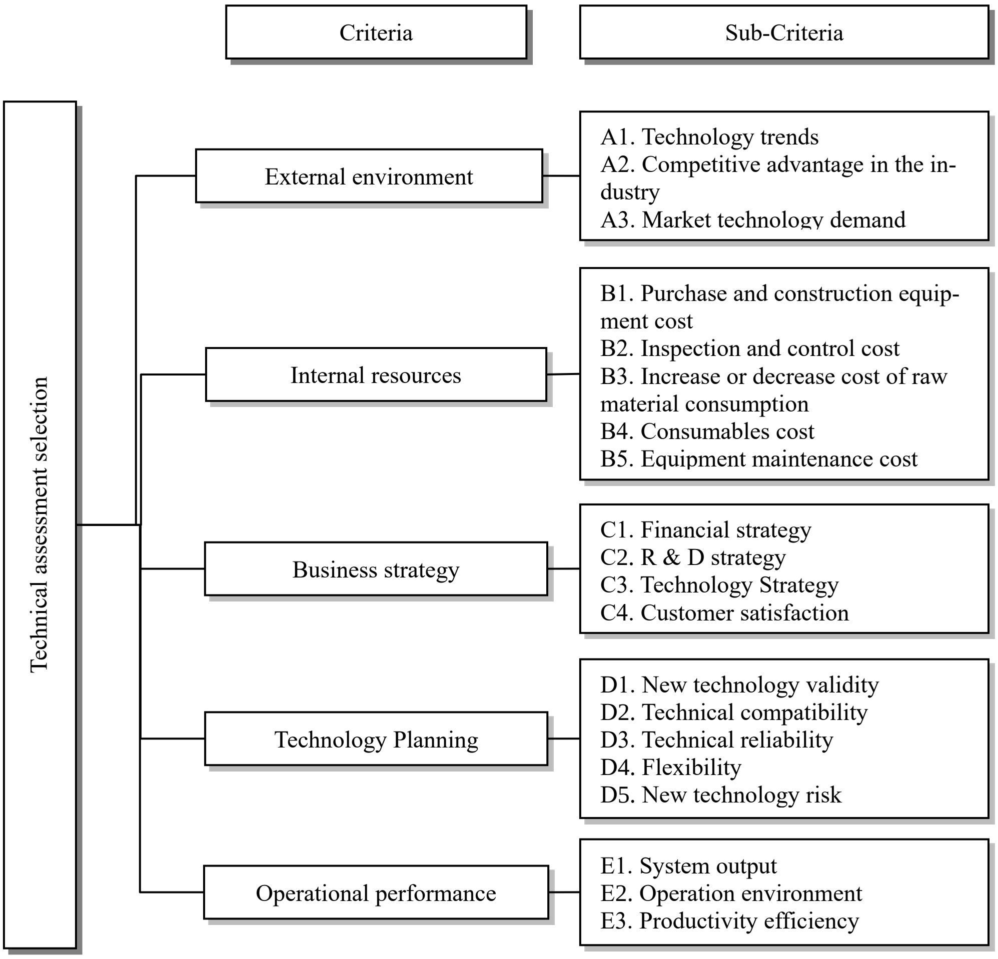

Figure 2: Evaluation Factor Hierarchy

The level analysis framework established through the first stage of evaluation criteria screening, and finally through ANP calculation to defuzzify each aspect and evaluation factor to obtain a clear evaluation value. The ranking of the important factors of each aspect evaluation factor is shown in the table 5 shown.

Table 5: Evaluation Factor Importance Ranking

Criteria	Sub-criteria	Number	Weight	Sort
External environment	Technology trends	A1	0.4224	2
	Competitive advantage in the industry	A2	0.3043	6
	Market technology demand	A3	0.2733	8
Internal resources	Purchase and construction equipment cost	B1	0.3517	5
	Inspection and control cost	B2	0.2431	11
	Increase or decrease cost of raw material consumption	B3	0.1742	13
	Consumables cost	B4	0.1373	17
	Equipment maintenance cost	B5	0.0937	20

Criteria	Sub-criteria	Number	Weight	Sort
Business strategy	Financial strategy	C1	0.4192	3
	R & D strategy	C2	0.2467	10
	Technology Strategy	C3	0.1715	14
	Customer satisfaction	C4	0.1626	15
Technology Planning	New technology validity	D1	0.3853	4
	Technical compatibility	D2	0.2078	12
	Technical reliability	D3	0.1429	16
	Flexibility	D4	0.1330	18
	New technology risk	D5	0.1309	19
Operational performance	System output	E1	0.4607	1
	Operation environment	E2	0.2812	7
	Productivity efficiency	E3	0.2581	9

5. Conclusion

In this study, the "Delphi Method" and "Analytic Network Process Method" of expert evaluation methods were used to conduct expert questionnaire surveys to construct an evaluation model when a manufacturer introduces new technologies. The research results can be summarized as the following conclusions:

(1) This study plans to construct a set of evaluation criteria for the introduction of 3D printing technology factors for Taiwan mold manufacturers, with a total of five dimensions. There are a total of 32 factors in the evaluation item, and 12 factors are filtered through the fuzzy Delphi expert questionnaire method to establish a hierarchical structure for the manufacturer's technology introduction evaluation, and then through the expert questionnaire level analysis to obtain the ranking of the evaluation criteria of importance.

(2) According to the importance of expert opinion standards, "System output", "Technology trends", "Financial strategy" and "New technology validity" are the most important-important factors for manufacturers to evaluate the introduction of new technologies. Overall, the evaluation value of this factor is also the highest. With the rapid update of technical equipment and the increase in customer demand, mold manufacturers are paying attention to the technological trends of 3D technology in process improvement, and attach the most importance to the efficiency and technological trends of equipment, and the evaluation factors in this study are also the most important. In addition, there are related financial costs. Since most of Taiwan's mold manufacturers are small and medium-sized manufacturers, and high-end business models have relatively high investment in 3D printing equipment, decision makers need to consider whether they have the financial situation to introduce 3D printing technology and capabilities. In addition, the results of this study also show that Taiwan mold manufacturers are also very willing to introduce new technologies in the same industry competition environment.

(3) Usually, the use of hierarchical analysis method must consider that the relevant factors of the problem are independent and have no mutual influence. Therefore, if there is a mutual influence relationship between the various factors, then the analytic network process can be considered.

Finally, this study provides an analysis of key factors for Taiwan mold manufacturers to evaluate the introduction of 3D process technology for decision-making reference. Due to time and environment constraints, follow-up research can be based on the conclusions of this research, comparing other evaluation models applied to other corporate functions such as R&D, human resources, finance and marketing, etc., through the adjustment of evaluation dimensions and criteria, as a more Decision support system for comprehensive evaluation.

References

Awasthi, A., Govindan, K., & Gold, S. (2018). Multi-tier sustainable global supplier selection using a fuzzy AHP-VIKOR based approach. *Int. J. Prod. Econ., 195*, 106-117.

Agrawal, A.; Seh, A.H.; Baz, A.; Alhakami, H.; Alhakami, W.; Baz, M.; Kumar, R.; Khan, R.A. Software Security Estimation Using the Hybrid Fuzzy ANP-TOPSIS Approach: Design Tactics Perspective. Symmetry 2020, 12, 598.

Betz, F. (2011). *Managing technological innovation: competitive advantage from change* (3 rd.). New Jersey: John Wiley & Sons.

Buckley, J. J. (1985). Fuzzy Hierarchical Analysis. *Fuzzy Sets and Systems*, *17*, 343-350.

Calabrese, A., Costa, R., Levialdi, N., & Menichini, T. (2019). Integrating sustainability into strategic decision-making: A fuzzy AHP method for the selection of relevant sustainability issues. *Technol. Forecast. Soc. Chang., 139*, 155-168.

Chan, F. T. S., Chan, M. H., & Tang N. K. H., (2000). Evaluation methodologies for technology selection. *Journal of Materials Processing Technology, 107*, 330-337.

Chatterjee, P., & Stevi´c, Ž. (2019). A two-phase fuzzy AHP-fuzzy TOPSIS model for supplier evaluation in manufacturing environment. *Oper. Res. Eng. Sci. Theory Appl., 2*, 72-90.

Chen, L. J. & Small, M.H. (1994). Implementing Advanced Manufacturing Technology：An Integrated Planning Model. *Omega*, *22*(1), 91-103.

Cho, D., & Yu, P. (2000). Influential factors in the choice of technology acquisition mode: an empirical analysis of small and medium size firms in Korean telecommunication industry. *Technovation*, *20*(2), 691-704.

Chuang, M.-K., Yang, Y.-S., & Lin, C.-T. (2009). Production technology selection: Deploying market requirements, competitive and operational strategies, and manufacturing attributes. *International Journal of Computer Integrated Manufacturing*, *22*(4), 345-355.

Ellitan, L. (2007). The influence of manufacturing strategies and environmental munificence as moderators of technology manufacturing performance relationship: An Evidence from Indonesia. *Jurnal Manajemen Maranatha*, *6*(2), 60-84.

Hamdia, K. M., Arafa, M., & Alqedra, M. (2018). Structural damage assessment criteria for reinforced concrete buildings by using a Fuzzy Analytic Hierarchy Process. *Underground Space*, *3*(3), 243-249

Hsu, H.-M., & Chen, C.-T. (1996). Aggregation of fuzzy opinions under group decision making. *Fuzzy Sets and Systems*, *79*(3), 279-285.

Hemmati N, Rahiminezhad Galankashi M, Imani DM, Farughi H (2018) Maintenance policy selection: a fuzzy-ANP approach. *J Manuf Technol Manag 29*(7), 1253-1268.

Khan, A.A., Shameem, M., Kumar, R.R., Hussain, S., & Yan, X. (2019). Fuzzy AHP based prioritization and taxonomy of software process improvement success factors in global software development. *Appl. Soft. Comput., 83*, 105648.

Kochan, D., Chua, C. K., & Du, Z. H. (1999). Rapid prototyping issues in the 21st century. *Computers in Industry*, *39*, 3-10.

Lee, Y.-C., & Chou, C. J. (2016). Technology Evaluation and Selection of 3DIC Integration Using a Three-Stage Fuzzy MCDM. *Sustainability*, *8*, 114.

Mohonty, P. R., & Deshmukh, S.G. (1998). Advanced technology manufacturing selection: A strategic model for learning and evaluation. *International Journal of Production Economics*, *55*(3), 295-307

Pun, K. P., Tsang, Y. P., Choy, K. L., Tang, V., & Lam, H. Y. (2017). A Fuzzy-AHP-Based Decision Support System for Maintenance Strategy Selection in Facility Management. *Proceedings of PICMET '17: Technology Management for Interconnected World*. 978-1-890843- 36.

Robbins, S. P. (1994). *Management.* Prentice Hall Inc.

Rosochowski A., & Matuszak, A. (2000). Rapid tooling：The state of the art. *Journal of Materials Processing Technology*, *106*, 191-198.

Saaty, T. L. (1980). *The Analytic Hierarchy Process* (pp50.). New York, NY: McGraw-Hill.

Si, T., Wang, C., Liu, R., Guo, Y., Yue, S., & Ren, Y., (2020). Multi-criteria comprehensive energy efficiency assessment based on fuzzy-AHP method: A case study of post-treatment technologies for coal-fired units. *Energy, 200*, 117533.

Taylan, O., AlAmoudi, R., Kabli, M., Aljifri, A., Ramzi, F., & Herrera-Viedma, E. (2020). Assessment of Energy Systems Using Extended Fuzzy AHP, Fuzzy VIKOR, and TOPSIS Approaches to Manage Non-Cooperative Opinions. *Sustainability, 12*, 2745.

Zadeh, L. A. (1965). Fuzzy set. *Information and Control*, *8*, 338-353.

Zwick, R., Carlstein, E. & Budescu, D. V. (1987). Measures of similarity among fuzzy concepts: A comparative analysis. *International Journal of Approximate Reasoning*, *1*(2), 221-242.

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