Adoption of Additive Manufacturing Technology in Small and Medium – Scale Enterprises: A Technology Management Framework

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Abstract - Small and medium-scale enterprises (SMEs) play a big role in economic growth in developing countries like the Philippines. Thus, they need to adapt to the latest emerging technologies such as additive manufacturing technology (AMT). The main objective of this study is to formulate a technology management framework for the adoption of additive manufacturing technology in small and medium-scale enterprises. Pertinent data such as the profile of the experts in 3D printing technology, the challenges faced by small and medium-scale enterprises in the adoption of additive manufacturing technology, and other relevant information were collected through literature research, surveys, and interviews. Validated survey questionnaires were given to the experts of the said technology. For the analysis of data, statistical treatments such as descriptive statistics, t-test analysis nonparametric analysis, Delphi Technique, and Kendall Coefficient of Concordance were calculated. Findings show that generally, stakeholders are aware and ready to adopt additive manufacturing technology. Also, the adoption of additive manufacturing technology is generally acceptable to the stakeholders considering the benefits of AMT such as improvement in production, easier to operate the equipment, and more quickly in accomplishing tasks. Similarly, there is a stakeholder's high level of readiness in terms of facilities and infrastructure. There is an allotted space and budget for the equipment, materials, and other facilities improvement. The stakeholders are aware, ready, and willing to adopt additive manufacturing technology. Also, there is no significant difference in the perception of stakeholders in terms of their level of awareness, willingness, and readiness to adopt additive manufacturing technology. Overall, the respondents identified financial, organizational, technical, and operational, policy requirements, and external factors such as support from the government are the challenges faced by small and medium-scale enterprises in adopting additive manufacturing. Adopting additive manufacturing technology in small and medium-scale enterprises is technically, operational, and economically viable. It is important to note also that there is a high level of technical viability in the perception of the respondents. There is also a significant difference in the perception of technical viability and the position in the company, the educational attainment, and the nature of business. There is a low level of operational viability based on the perception of the respondents. This is due to their perception that the cost of the equipment and the integration in the operation is too high. Similarly, there is a high level of economic viability based on the perception of the respondents. Policy in training and development, quality assurance, improvement in facility and infrastructure, acquisition of new technology, safety and security, and maintenance must be formulated to ensure the success of the adoption of AMT. The management programs that should be considered to ensure the sustainability of the adoption of AMT in small and medium-scale enterprises are the economic, technical, operational, and management actions. The respondents perceived that the proposed roadmap would be effective and viable if there was support from the top management and the government.

Keywords - Technology Management: Additive Manufacturing Technology: Small and Medium Scale Enterprises: Additive Manufacturing: 3d Printing

Introduction

Around the world, traditional manufacturing is in the throes of a digital transformation that is accelerated by exponentially growing technologies. The pace of change reflects "Moore's Law" on the speed at which the transfer of technology-driven change happens. Small and medium-scale enterprises need to adapt to this rapid change if they are not to be left behind by developments in their sectors and their competitors. These tendencies should not be equated to a purely automated production process, which has been accelerated by industry 4.0 innovations. The widespread adoption by the manufacturing industry around the world of smart factories or the application of automation is now paving the way to disruptive approaches to development and production, an example of such is additive manufacturing. Over the past ten years, significant developments in additive manufacturing technology, often known as 3d printing, have changed the potential methods for product development, manufacturing, and distribution. Contrary

to conventional subtractive manufacturing techniques, additive manufacturing technology, also known as 3D printing technology, is the process of joining materials to build items from 3D model data, often layer by layer. Traditional manufacturing and supply chain paths will change because of new advances in AMT processes and related innovations in domains like advanced materials. These developments will also benefit production in many industries. In several industries, these advances have opened doors for newer designs; cleaner, lighter, and safer products; shorter lead times; and lower costs. Fewer design constraints, which frequently limit more conventional production procedures, can be produced by additive manufacturing technology. When creating products with unique features, this flexibility is very helpful because it enables the addition of better functionalities like integrated electrical wiring (through hollow structures), reduced weight (through lattice structures), and complex geometries that are not possible through conventional processes. New AM technologies may also progressively create printed items made of many materials that have unique characteristics like changeable strength and electrical conductivity. Future products will be made faster, safer, lighter, and more efficient thanks to AMT methods.

Background of the Study

Small and medium-sized enterprises (SMEs) contribute significantly to economic growth in developing nations such as the Philippines. According to Philippine Business Registry of Department of Trade and Industry (DTI), there are 1.5 million registered enterprises in the country and SMEs account for 25% of the country's total exports revenue. Due to the demand of globalization, SMSEs are now facing more challenging demand to upgrade than in past years (Sharma and Sharma, 2018; Singh, 2019). Previously, they just had to compete on price and quality, but now they must also compete on responsiveness and flexibility given the current industrial environment.

Statement of the Problem

The study aimed to formulate a technology management framework for the adoption of additive manufacturing technology in small and medium scale enterprises.

Specifically, the research sought answers to the following questions:

1. What is the level of awareness and readiness of different stakeholders on the adoption of additive manufacturing technology considering such as skills, expertise, and knowhow?
2. What is the level of acceptability of additive manufacturing technology to stakeholders?
3. What is the level of readiness of small and medium-scale enterprises in terms of facilities and infrastructure in implementing additive manufacturing technology?
4. Is there a significant difference in the perception of the different stakeholders in terms of their level of awareness, willingness, and readiness to adopt additive manufacturing technology and their perception in different issues/problems in the adoption of additive manufacturing technology when grouped according to their demographic profile?
5. What challenges are faced/encountered by small and medium-scale enterprises in the adoption of additive manufacturing technology?
6. What is the viability of adopting additive manufacturing technology in small and medium-scale enterprises in terms of:
    a. Technical Factors
    b. Operational Factors
    c. Economics Factors

Materials and Methods

The research design, population sample, research tools, data collection techniques, and statistical analysis of the data that were systematically used in carrying out this study are presented in this area.

Research Design

This study employed a mixed method sequential explanatory design with two separate phases: quantitative and qualitative (Creswell, et al 2003). The quantitative results obtained in the first phase are explained or expanded upon by the qualitative data, which were collected and processed second in the sequence.

Population and Sample

In total, twenty responses were received from industry experts via interviews. The number of responses is sufficient for this research purpose to increase understanding of the research topic and to formulate the research paradigm. The interviews were mainly exploratory, finding out some of the implications of the adoption of additive manufacturing technology and best practices that might be difficult to come by in the literature.

The interviewed representatives were chosen based on their professional background and expertise. The experts hold responsible positions in management activities related to the adoption of additive manufacturing and their up-to-date knowledge of the research topics. The job titles of the respondents include the following: CEO, managers, supervisors, and other top administrators of any SME. Suppliers of 3D printing machines were also considered, as government personnel who have expertise in AM technology, and mechanical engineers who have ample knowledge in adopting additive manufacturing technology in SME processes.

In addition, surveys were done to collect data from different stakeholders' representatives.

Statistical Treatment of Data
Statistical treatment of data depends upon the nature of the problem, specifically the specific problems and the nature of data gathered. The proponent used the following statistical treatment:

1. Percentage. The frequencies of the population of the study were computed in percentage. It was used to determine the profile of the respondents as regards to age, number of years in business, position, highest educational attainment and sales in the previous years.
1. 2. Weighted Mean. The researcher computed the mean
2. X, which is defined as the sum of all values of a given parameter, divided by the number of data in the sample. It was used to compute the average data of the samples taken.
3. t-test. For the purpose of testing the null hypothesis and to determine whether or not there is a significant difference in the perceived problems by the respondents when they are grouped according to profile variables.
4. Analysis of Variance (ANOVA). For the purpose of testing the null hypothesis and to determine whether or not there is a significant difference of more than two groups to compare, ANOVA was used.
5. Delphi Method

The qualitative method was used to answer research questions regarding the problems and challenges faced/ encountered by small and medium scale enterprises in the adoption of additive manufacturing technology. Using Delphi method, the researcher gathered information from experts. Based on the expertise and experiences of the group of experts, the Delphi method was used as strategy in making decisions. Typically, a consensus is reached after rounds of inquiries.

The Delphi method allows experts to give their thoughts anonymously without interaction or interference. Opinions are formed depending on the judgment and merit of individual. After collecting replies, the researcher delivers anonymous comments to the participants on the responses that were not on agreement. The participants evaluate the input and may change their minds about the previous responses.

There were 20 experts invited to participate in the Delphi survey. Experts from shared-service facility recipients, from faculty who are familiar with the technology, experts from Department of Trade and Industry (DTI) and other government agencies and small and medium scale enterprises owners/engineers who has/knows 3D printing.

Kendall's Coefficient of Concordance

This statistic is non-parametric. It is a normalization of the Friedman test statistic and can be used to gauge rater agreement. The range of Kendall's W is 0 (no agreement) to 1. (complete agreement). These numbers can be used to determine Kendall's W. If the test statistic W is 1, then all survey participants have agreed and have ranked the list of concerns in the same order. If W is zero, the participants' responses can be taken to be essentially random because there is no overall tendency of agreement among them. Greater or less agreement among the various responses is indicated by intermediate values of W.

Results and Discussions

Table 1: Level of Awareness and Readiness of Different Stakeholders on the Adoption of Additive Manufacturing Considering such as Skills, Expertise, and Knowhow

Awareness	Mean	SD	Verbal Interpretation	Rank
1. What is the general (company-wide) attitude towards the changes in your business processes?	4.38	0.87	Agree	2
2. Our company has allocated a budget for research and development on additive manufacturing technology	3.94	1.19	Agree	3
3. Our company has prepared for the adoption of 3D Printing by sending employees to train in 3D Printing.	4.54	0.50	Completely Agree	1
4. Our company has prepared the logistical support to develop and implement 3D Printing.	3.64	1.32	Agree	4
5. The company is aware of the government support for 3D Printing	2.41	1.20	Neutral	7
6. The company has identified the processes where 3D Printing can be applied.	3.00	1.38	Neutral	5
7. The company believes that 3D Printing can enhance the competitiveness of the company in the industry.	2.63	1.18	Neutral	6
Composite Mean	**3.79**	**0.51**	**Aware**	

a. Level of Acceptability in Adopting Additive Manufacturing Technology

Additive manufacturing technology's acceptability is the user's adequacy to employ technology for the tasks it is designed to support.

Acceptability	Mean	SD	Verbal Interpretation	Rank
1. Additive manufacturing technology is easier to operate compared to traditional manufacturing	3.68	0.34	Agree	3.5
2. Additive manufacturing will enable me to accomplish tasks more quickly	3.78	0.36	Agree	2
3. Additive manufacturing will allow our company to be highly competitive in the industry	4.95	0.37	Completely Agree	1
4. Using 3D printers allow me to accomplish task that would be otherwise impossible	3.10	1.45	Neutral	4
5. It's the company's view that additive manufacturing will improve production.	3.68	0.43	Agree	3.5
Composite Mean	**3.84**	**0.59**	**Accept**	

b. Level of Readiness to Adopting Additive Manufacturing Technology in terms of Facilities and Infrastructure

Additive manufacturing technology's readiness is the user's preparedness to employ technology for the tasks it is designed to support.

Table 3: Level of Readiness in terms of Facilities and Infrastructure

Readiness	Mean	SD	Verbal Interpretation	Rank
1. The company has allotted storage/space for the 3D equipment and supply.	2.57	1.34	Neutral	9
2. The company has allotted a budget for facility and infrastructure improvement.	2.67	1.43	Neutral	8
3. Our company officers have complete control over the implementation, maintenance, and adoption of additive manufacturing	3.04	1.44	Neutral	7
4. Our company officers are fully aware of the benefits of additive manufacturing.	4.32	1.02	Agree	4
5. Our company officers have extensive background and experience in additive technology and are receptive to additive manufacturing	4.37	0.64	Agree	3
6. Our supervisors and rank and file are aware of the latest technology that can be adopted such as 3D Printing to improve production.	4.04	1.02	Agree	6
7. The inclusion of additive manufacturing in our processes will attain the objective of reducing variation in our manufacturing processes.	4.15	0.93	Agree	5
8. There are processes in the company where 3D Printing can be applied	4.45	1.04	Agree	2
9. 3D Printing is expensive.	4.60	0.67	Completely Agree	1
Composite Mean	3.80	0.53	Ready	

II. Viability Adopting Additive Manufacturing in Small and Medium-Scale Enterprises

Table 4: Perceived Technical Viability in Adopting Additive Manufacturing

Technical	**Mean**	**SD**	**Verbal Interpretation**	**Rank**
1. Our company has prepared for the adoption of 3D Printing by hiring experts and sending employees to train in 3D Printing	4.88	0.38	Completely Agree	1
2. The company officers are fully aware of the benefits of 3D printing in the implementation of additive manufacturing.	4.38	0.87	Agree	4
3. Our company has allocated a budget for research and development on additive manufacturing technology	3.94	1.19	Agree	5
4. Our company is aware of the general design consideration and list of red flags for design specifications mentioned in AM standard.	4.54	0.50	Completely Agree	2
5. The company has seen that AM technology has been widely used in commercial production techniques and is widely accepted	3.64	1.32	Agree	6
6. Our company has prepared the logistical support to develop and implement 3D Printing.	4.41	0.90	Agree	3
Composite Mean	**4.30**	**0.37**	**Viable**	

Table 5: Perceived Operational Viability in Adopting Additive Manufacturing

Operational	Mean	SD	Verbal Interpretation	Rank
1. The company has ample space for equipment and supplies.	3.00	1.38	Neutral	2
2. The company officers are aware of the AM technology that can be adopted to improve the design of the product.	4.63	0.36	Completely Agree	1
3. The integration of additive manufacturing in our processes will attain the objective of reducing variation in our manufacturing processes.	2.68	1.34	Neutral	5
4. The company has provisions for the maintenance of the adoption of additive manufacturing.	2.78	1.36	Neutral	4
5. To improve quality, the company is continuously making improvements and reducing the quality problems in the product and processes which can be achieved with the help of 3D Printing.	2.95	1.37	Neutral	3
Composite Mean	**2.81**	**0.98**	**Uncertain**	

Table 6: Perceived Economic Viability in Adopting Additive Manufacturing

Economics	Mean	SD	Verbal Interpretation	Rank
1. Our company is aware of the financial benefits of adopting 3d printing technology	3.09	1.45	Neutral	5
2. The company is aware of the cost operation and integration upon adopting the new technology.	4.39	0.86	Agree	2
3. It is possible to eliminate non-value-added costs associated with all the operations upon the adoption of AM technology.	3.94	1.18	Agree	3
4. The company has allotted a budget for facility and infrastructure upon the adoption of additive manufacturing.	3.65	1.32	Agree	4
5. Our company cannot afford 3D Printing	4.41	0.90	Agree	1
6. The company has allotted a budget for the improvement of the facility and infrastructure upon the adoption of additive manufacturing.	3.00	1.38	Neutral	6
7. Our company has allocated a budget for research and development on additive manufacturing technology and for the training of personnel.	2.63	1.18	Neutral	7
Composite Mean	**3.71**	**0.53**	**Viable**	

III. Perception of the Respondents in terms of Level of Awareness, Acceptability, and Readiness to Adopt Additive Manufacturing in SMEs when Grouped According to their Demographic Profile

Table 7: Analysis of Variance of the Level of Awareness to Adopt Additive Manufacturing in SMEs when Grouped According to their Demographic Profile

Age	Mean	SD	p-value	Interpretation
21-33	3.84	0.54	0.6899	Not Significant
34-46	3.75	0.42		
47-59	3.79	0.54		
60 and above	3.69	0.57		

Gender				
Female	3.82	0.48	0.5403	Not Significant
Male	3.8	0.53		
Marital Status				
Single	3.78	0.54	0.885	Not Significant
Married	3.79	0.51		
Profession				
Engineer	3.85	0.51	0.242	Not Significant
Business	3.81	0.47		
Accountant	3.64	0.45		
Others	3.69	0.6		
Position in the Company				
CEO/COO/Owners	3.67	0.46	0.0241*	Significant
Managers	3.67	0.53		
Supervisors	3.77	0.45		
AM Specialists/Experts	3.89	0.57		
Engineers	3.94	0.53		
Number of Years' Experience in tech department				
1 to 9	3.83	0.5	0.3208	Not Significant
10 to 18	3.81	0.51		
19 to 27	3.64	0.52		
37 and above	3.79	0.64		
Educational Attainment				
High School	3.7	0.61	0.2402	Not Significant
Tech-Voc	3.54	0.52		
Bachelor	3.85	0.5		
Masters	3.75	0.5		
Doctorate	3.7	0.46		
Number of years of Experience in Tech Management				
1 to 9	3.83	0.5	0.3208	Not Significant
10 to 18	3.81	0.51		
19 to 27	3.64	0.52		
37 and above	3.79	0.64		
Number of years of experience in 3D Printing				
1 to 5	3.76	0.5	0.1388	Not Significant
6 to 10	3.94	0.49		
11 and above	3.77	0.59		
Nature of Business				
Manufacturing	3.79	0.48	0.0123*	Significant
Processed Foods	3.76	0.55		
Fabrication	3.68	0.37		
Herbal	3.39	0.54		
Academe	3.99	0.54		
Government Agency	4.02	0.51		

Number of years of operation				
2 to 10	3.82	0.5	0.1911	Not Significant
11 to 19	3.82	0.53		
20 to 28	3.6	0.49		
38 and above	3.79	0.64		
Number of Employees				
7 to 25	3.79	0.5	0.3622	Not Significant
26 to 44	3.72	0.55		
45 to 63	4	0.51		
64 to 82	3.97	0.62		
83 and above	3.8	0.24		

Null hypothesis: There is no significant difference in the awareness of the respondents when grouped according to demographic profile. If p-value is < 0.05, reject the null.

The table above shows that the differences in the awareness of the respondents exist only when grouped according to position in their company and nature of business. The rest of the demographics have no significant result. This shows that the awareness of the respondents depends only on their position in the company and nature of business. The descriptive statistics show that engineers have the highest level of awareness as opposed to other positions while the CEO and Managers have the lowest level of awareness. In terms of nature of business, the government agencies have the highest level of awareness while those who are in herbal business have the lowest level of awareness.

Table 8: Analysis of Variance of the Level of Acceptability to Adopt Additive Manufacturing in SMEs when Grouped According to their Demographic Profile

Age	**Mean**	**SD**	**p-value**	**Interpretation**
21-33	2.73	0.96	0.4768	Not Significant
34-46	2.81	0.98		
47-59	2.97	1.03		
60 and above	2.84	0.99		
Gender				
Female	2.70	1.02	0.1612	Not Significant
Male	2.90	0.97		
Marital Status				
Single	2.49	0.91	0.0603	Not Significant
Married	2.89	0.99		
Profession				
Engineer	2.96	0.99	0.2433	Not Significant
Business	2.68	0.96		
Accountant	3.01	1.21		
Others	2.88	0.96		
Position in the Company				
CEO/COO/Owners	2.83	0.94	0.7847	Not Significant
Managers	2.66	0.89		
Supervisors	2.81	1.02		
AM Specialists/Experts	2.91	1.05		
Engineers	2.93	1.03		

Educational Attainment				
High School	3.70	0.61	0.2402	Not Significant
Tech-Voc	3.54	0.52		
Bachelor	3.85	0.50		
Masters	3.75	0.50		
Doctorate	3.70	0.46		
Number of years of Experience in Tech Management				
1 to 9	2.95	1.00	0.0155*	Significant
10 to 18	2.85	1.02		
19 to 27	2.32	0.74		
37 and above	3.02	0.99		
Number of years of experience in 3D Printing				
1 to 5	2.86	0.98	0.049*	Significant
6 to 10	3.02	1.04		
11 and above	2.41	0.85		
Nature of Business				
Manufacturing	2.82	0.97	0.6035	Not Significant
Processed Foods	2.72	0.99		
Fabrication	2.88	1.06		
Herbal	2.73	0.89		
Academe	3.11	1.07		
Government Agency	2.70	0.84		
Number of years of operation				
2 to 10	2.97	1.00	0.0062*	Significant
11 to 19	2.83	0.99		
20 to 28	2.26	0.73		
38 and above	3.02	0.99		
Number of Employees				
7 to 25	2.77	0.93	0.0114*	Significant
26 to 44	2.87	1.02		
45 to 63	3.48	1.19		
64 to 82	3.34	1.19		
83 and above	1.96	0.41		

The table above indicates that the differences in the acceptability of the respondents exist only when grouped according to number of years' experience in technology management, number of years of operation, and number of employees. The rest of the demographics have no significant result. This shows that the acceptability of the respondents depends on the number of years' experience in technology management, number of years of operation, and number of employees. The descriptive statistics show that those with 37 and above number of years of experience in technology management has the highest level of acceptability while the lowest are those with 19-27 years of experience. In terms of number of years of experience in 3D printing, those working for 6-10 years has the highest level of acceptability while those 11 and above has the lowest. The highest level of acceptability for the number of years of operation are those operating for 36 years and above while the lowest are those operating for 20-28 years. For the number of employees, the highest level of acceptability are those with 45 to 63 employees while the lowest are those with 83 and above employees.

Table 9: Analysis of Variance of the Level of Readiness to Adopt Additive Manufacturing in SMEs when Grouped According to their Demographic Profile

Age	Mean	SD	p-value	Interpretation
21-33	3.82	0.45	0.5195	Not Significant
34-46	3.79	0.62		
47-59	3.76	0.52		
60 and above	4.01	0.52		
Gender				
Female	3.72	0.42	0.1013	Not Significant
Male	3.84	0.57		
Marital Status				
Single	3.69	0.41	0.2153	Not Significant
Married	3.82	0.54		
Profession				
Engineer	3.82	0.55	0.979	Not Significant
Business	3.79	0.51		
Accountant	3.81	0.42		
Others	3.77	0.57		
Position in the Company				
CEO/COO/Owners	3.84	0.52	0.8896	Not Significant
Managers	3.83	0.50		
Supervisors	3.81	0.60		
AM Specialists/Experts	3.73	0.49		
Engineers	3.77	0.51		
Number of years experience in tech department				
1 to 9	3.81	0.55	0.7218	Not Significant
10 to 18	3.74	0.51		
19 to 27	3.85	0.49		
37 and above	3.88	0.47		
Educational Attainment				
High School	3.74	0.56	0.8114	Not Significant
Tech-Voc	3.90	0.66		
Bachelor	3.81	0.50		
Masters	3.73	0.60		
Doctorate	3.88	0.55		
Number of years of Experience in Tech Management				
1 to 9	3.81	0.55	0.7218	Not Significant
10 to 18	3.74	0.51		
19 to 27	3.85	0.49		
37 and above	3.88	0.47		
Number of years of experience in 3D Printing				
1 to 5	3.84	0.53	0.1774	Not Significant

6 to 10	3.66	0.54		
11 and above	3.78	0.45		
Nature of Business				
Manufacturing	3.79	0.49	0.0048*	Significant
Processed Foods	3.81	0.48		
Fabrication	3.82	0.75		
Herbal	4.37	0.54		
Academe	3.64	0.46		
Government Agency	3.69	0.61		
Number of years of operation				
2 to 10	3.82	0.56	0.6907	Not Significant
11 to 19	3.74	0.49		
20 to 28	3.83	0.52		
38 and above	3.88	0.47		
Number of Employees				
7 to 25	3.77	0.53	0.3439	Not Significant
26 to 44	3.83	0.56		
45 to 63	4.06	0.45		
64 to 82	3.89	0.48		
83 and above	3.64	0.32		

The table above shows that the differences in the readiness of the respondents exist only when grouped according to nature of business. The rest of the demographics have no significant result. This shows that the readiness of the respondents depends only on their nature of business. The descriptive statistics show that in terms of nature of business, the herbal business have the highest level of readiness while those who are in academe have the lowest level of readiness.

IV. Perception of the Respondents on the Viability of Adopting Additive Manufacturing in the Small and Medium-Scale Enterprises when Grouped According to Demographic Profile

Table 10: Analysis of Variance on the Technical Viability in the Adoption of AM when Grouped According to Demographic Profile

Age	Mean	SD	p-value	Interpretation
21-33	4.37	0.37	0.2163	Not Significant
34-46	4.28	0.34		
47-59	4.27	0.37		
60 and above	4.20	0.42		
Gender				
Female	4.29	0.36	0.7214	Not Significant
Male	4.31	0.37		
Marital Status				
Single	4.27	0.42	0.6351	Not Significant
Married	4.30	0.36		
Profession				

Engineer	4.37	0.32	0.0526	Not Significant
Business	4.30	0.35		
Accountant	4.21	0.25		
Others	4.18	0.48		
Position in the Company				
CEO/COO/Owners	4.23	0.38	0.0463*	Significant
Managers	4.25	0.40		
Supervisors	4.27	0.34		
AM Specialists/Experts	4.28	0.36		
Engineers	4.42	0.34		
Number of years' experience in tech department				
1 to 9	4.33	0.33	0.1073	Not Significant
10 to 18	4.31	0.40		
19 to 27	4.15	0.39		
37 and above	4.33	0.41		
Educational Attainment				
High School	4.22	0.46	0.0457*	Significant
Tech-Voc	4.02	0.51		
Bachelor	4.34	0.32		
Masters	4.27	0.40		
Doctorate	4.29	0.32		
Number of years of Experience in Tech Management				
1 to 9	4.33	0.33	0.1073	Not Significant
10 to 18	4.31	0.40		
19 to 27	4.15	0.39		
37 and above	4.33	0.41		
Number of years of experience in 3D Printing				
1 to 5	4.28	0.36	0.3633	Not Significant
6 to 10	4.38	0.33		
11 and above	4.29	0.42		
Nature of Business				
Manufacturing	4.35	0.34	0.0002*	Highly Significant
Processed Foods	4.27	0.39		
Fabrication	4.12	0.23		
Herbal	3.89	0.37		
Academe	4.39	0.36		
Government Agency	4.42	0.31		
Number of years of operation				
2 to 10	4.33	0.33	0.0783	Not Significant
11 to 19	4.31	0.40		
20 to 28	4.14	0.39		
38 and above	4.33	0.41		
Number of Employees				
7 to 25	4.29	0.38	0.2961	Not Significant

26 to 44	4.25	0.33
45 to 63	4.46	0.31
64 to 82	4.37	0.41
83 and above	4.47	0.30

The table above shows that the differences in the perception of the respondents regarding the technical viability of adopting AM only when grouped according to position in their company, educational attainment, and nature of business. The rest of the demographics have no significant result. This shows that the differences in the perception of the respondents regarding the technical viability of adopting AM depend on when grouped according to position in their company, educational attainment, and nature of business. The descriptive statistics show that engineers have the highest level of perception regarding the technical viability of AM as opposed to other positions while the CEO /COO/ owners have the lowest level. Those graduates with bachelor degrees have the highest level while tech-voc graduates have the lowest. In terms of the nature of business, the government agencies have the highest level while those who are in the herbal business have the lowest level.

Table 11: Analysis of Variance on the Operational Viability in the Adoption of AM when Grouped According to Demographic Profile

Age	Mean	SD	p-value	Interpretation
21-33	4.37	0.37	0.2163	Not Significant
34-46	4.28	0.34		
47-59	4.27	0.37		
60 and above	4.20	0.42		
Gender				
Female	4.29	0.36	0.7214	Not Significant
Male	4.31	0.37		
Marital Status				
Single	4.27	0.42	0.6351	Not Significant
Married	4.30	0.36		
Profession				
Engineer	4.37	0.32	0.0526	Not Significant
Business	4.30	0.35		
Accountant	4.21	0.25		
Others	4.18	0.48		
Position in the Company				
CEO/COO/Owners	4.23	0.38	0.0463*	Significant
Managers	4.25	0.40		
Supervisors	4.27	0.34		
AM Specialists/Experts	4.28	0.36		
Engineers	4.42	0.34		
Number of years experience in tech department				
1 to 9	4.33	0.33	0.1073	Not Significant
10 to 18	4.31	0.40		
19 to 27	4.15	0.39		
37 and above	4.33	0.41		
Educational Attainment				
High School	4.22	0.46	0.0457*	Significant

Tech-Voc	4.02	0.51		
Bachelor	4.34	0.32		
Masters	4.27	0.40		
Doctorate	4.29	0.32		
Number of years of Experience in Tech Management				
1 to 9	4.33	0.33	0.1073	Not Significant
10 to 18	4.31	0.40		
19 to 27	4.15	0.39		
37 and above	4.33	0.41		
Number of years of experience in 3D Printing				
1 to 5	4.28	0.36	0.3633	Not Significant
6 to 10	4.38	0.33		
11 and above	4.29	0.42		
Nature of Business				
Manufacturing	4.35	0.34	0.0002*	Highly Significant
Processed Foods	4.27	0.39		
Fabrication	4.12	0.23		
Herbal	3.89	0.37		
Academe	4.39	0.36		
Government Agency	4.42	0.31		
Number of years of operation				
2 to 10	4.33	0.33	0.0783	Not Significant
11 to 19	4.31	0.40		
20 to 28	4.14	0.39		
38 and above	4.33	0.41		
Number of Employees				
7 to 25	4.29	0.38	0.2961	Not Significant
26 to 44	4.25	0.33		
45 to 63	4.46	0.31		
64 to 82	4.37	0.41		
83 and above	4.47	0.30		

The table above shows that the differences in the perception of the respondents regarding the operational viability of adopting AM only when grouped according to position in their company, educational attainment, and nature of business. The rest of the demographics have no significant result. This shows that the differences in the perception of the respondents regarding the operational viability of adopting AM depends on when grouped according to position in their company, educational attainment, and nature of business. The descriptive statistics show that engineers have the highest level of perception regarding operational viability of AM as opposed to other positions while the CEO /COO/ owners have the lowest level. Those graduates of bachelor's degree have the highest level while tech-voc graduates has the lowest. In terms of nature of business, the fabrication has the highest level while those who are in herbal business have the lowest level.

Table 12: Analysis of Variance on the Economic Viability in the Adoption of AM when Grouped According to Demographic Profile

Age	Mean	SD	p-value	Interpretation
21-33	3.73	0.57	0.7284	Not Significant

34-46	3.66	0.45		
47-59	3.74	0.55		
60 and above	3.60	0.57		
Gender				
Female	3.71	0.51	0.9191	Not Significant
Male	3.70	0.54		
Marital Status				
Single	3.63	0.57	0.3749	Not Significant
Married	3.72	0.53		
Profession				
Engineer	3.78	0.56	0.3465	Not Significant
Business	3.69	0.46		
Accountant	3.58	0.49		
Others	3.62	0.62		
Position in the Company				
CEO/COO/Owners	3.60	0.44	0.0333*	Significant
Managers	3.57	0.54		
Supervisors	3.66	0.50		
AM Specialists/Experts	3.81	0.55		
Engineers	3.85	0.58		
Number of years experience in tech department				
1 to 9	3.75	0.53	0.0752	Not Significant
10 to 18	3.72	0.52		
19 to 27	3.48	0.48		
37 and above	3.73	0.62		
Educational Attainment				
High School	3.66	0.62	0.3019	Not Significant
Tech-Voc	3.40	0.51		
Bachelor	3.75	0.53		
Masters	3.67	0.47		
Doctorate	3.63	0.43		
Number of years of Experience in Tech Management				
1 to 9	3.75	0.53	0.0752	Not Significant
10 to 18	3.72	0.52		
19 to 27	3.48	0.48		
37 and above	3.73	0.62		
Number of years of experience in 3D Printing				
1 to 5	3.68	0.52	0.0955	Not Significant
6 to 10	3.86	0.55		
11 and above	3.60	0.57		
Nature of Business				
Manufacturing	3.70	0.49	0.0194*	Significant
Processed Foods	3.66	0.58		
Fabrication	3.60	0.45		

Herbal	3.35	0.50		
Academe	3.93	0.56		
Government Agency	3.94	0.53		
Number of years of operation				
2 to 10	3.75	0.53	0.0331*	Significant
11 to 19	3.73	0.53		
20 to 28	3.44	0.45		
38 and above	3.73	0.62		
Number of Employees				
7 to 25	3.69	0.49	0.1392	Not Significant
26 to 44	3.65	0.60		
45 to 63	3.98	0.56		
64 to 82	3.95	0.69		
83 and above	3.52	0.21		

The table above indicates that the differences in the perception of the respondents regarding the economic viability of adopting AM only when grouped according to position in their company, nature of business, and number of years of operation. The rest of the demographics have no significant result. This shows that the differences in the perception of the respondents regarding the economic viability of adopting AM depends on when grouped according to position in their company, nature of business, and number of years of operation. The descriptive statistics show that engineers have the highest level of perception regarding economic viability of AM as opposed to other positions while the managers have the lowest level. In terms of nature of business, the government agencies have the highest level while those who are in herbal business have the lowest level. Those who are operating for 2-10 years has the highest level while those operating for 20-28 years has the lowest.

V. Challenges Faced/ Encountered by Small and Medium Enterprises in Adopting Additive Manufacturing Technology

Identification of the Criteria for the Adoption of Additive Manufacturing by Expert Participants: The Delphi Consensus

The following are the identified criteria based on the feedback of the panel participants. The factors identified for the development of a technology framework include challenges, policy requirements, sustainability, technical, and socio-economic.

Delphi Round 1: Identification of the Criteria on the Challenges

CHALLENGES

1. The amount of cost needed to acquire, procure, implement, and maintain 3d printers.
2. The number of employees that will maintain the system
3. There is a stakeholders' resistance to change
4. Selecting the employees to be trained
5. Lack of AM personnel/experts within organization
6. Capacity to train staff
7. Cost of Integration
8. Cost of facility improvement and infrastructure
9. Capacity to select and install a software to be used
10. Integration in the system
11. Ensuring quality of output during integration
12. Identifying appropriate 3D printers to be used
13. Awareness of government support

14. Manual post processing
15. Ease of Use
16. Software challenges
17. Concern about loss of productivity during transition to the new system
18. Improper storing of materials/filaments
19. Limited budget for research and development

These are challenges/factors play a role in adoption of new technology in any organization based on the assessments of the experts. It is necessary to analyze and assess these factors based on the opinions of experts to formulate better programs to address the challenges faced.

Table 13: Responses of Expert Participants in Round Two for Challenges

Statements	Mean	Std. Deviation	Min	Max
1. The amount of cost needed to acquire, procure, implement, and maintain 3d printers.	2.65	1.45521	1	5
2. The number of employees that will maintain the technology	6.47	1.00733	1	4
3. There is a stakeholders' resistance to change	2.94	1.59963	1	7
4. Selecting the employees to be trained	2.71	1.26317	1	5
5. Lack of AM personnel/experts within organization	2.47	0.71743	5	7
6. Capacity to train staff	6.71	1.1048	1	5
7. Cost of Integration	2.59	1.22774	1	5
8. Cost of facility improvement and infrastructure	2.71	0.46967	6	7
9. Capacity to select and install a software to be used	6.18	0.88284	5	7
10. Integration in the system	2.82	1.07444	1	4
11. Ensuring quality of output during integration	1.82	0.88284	1	4
12. Identifying appropriate 3D printers to be used	2.12	1.45269	2	7
13. Awareness of government support	2.71	1.35585	1	5
14. Manual post processing	6.83	1.13111	1	5
15. Ease of Use	2.18	1.46779	2	7
16. Software challenges	6.47	0.62426	1	4
17. Concern about loss of productivity during transition to the new system	1.88	0.78121	1	4
18. Improper storing of materials/filaments	6.47	1.12459	1	4
19. Limited budget for research and development	2.76	1.39326	1	5
Kendall's W	**0.651**			

The table above shows the result of the consensus of the panel expert about the importance of the statements for the challenges in adopting additive manufacturing in small and medium scale enterprises.

Based on the results, the mean obtained for the number of employees that will maintain the technology (6.47), capacity to train staffs (6.71), capacity to install software to be used (6.18), manual post processing (6.83), software challenges (6.47), and improper storing of materials and filaments (6.47) were considered unimportant using the semantic scale of 7.

Round 2 obtained Kendall's Coefficient of concordance at 0.651 indicating lack of agreement between panel experts in rating the criteria since the researcher would like to obtain Kendall's coefficient of concordance at 0.7.

Table 14: Components of Proposed Technology Management Framework to Address the Challenges Faced/ Encountered by Small and Medium Enterprises in Adopting Additive Manufacturing Technology (Round 3)

Statements	Mean	Std. Deviation	Min	Max
1. The amount of cost needed to acquire, procure, implement, and maintain 3d printers.	1.00	0.0000	1	1
2. There is a stakeholders' resistance to change	1.00	0.0000	1	1
3. Selecting the employees to be trained	2.00	0.0000	2	2
4. Lack of AM personnel/experts within organization	1.00	0.0000	1	1
5. Cost of Integration	2.00	0.0000	2	2
6. Cost of facility improvement and infrastructure	3.00	0.0000	3	3
7. Integration in the system	1.00	0.0000	1	1
8. Ensuring quality of output during integration	1.00	0.0000	1	1
9. Identifying appropriate 3D printers to be used	2.00	0.0000	2	2
10. Awareness of government support	1.06	0.23550	1	2
11. Ease of Use	2.18	1.46779	2	7
12. Concern about loss of productivity during transition to the new system	1.00	0.0000	1	1
13. Limited budget for research and development	1.00	0.0000	1	1
Kendall's W	**0.94**			

Round 3 obtained Kendall's Coefficient of concordance at 0.940 indicating the strong agreement between panel experts in rating the criteria which means that the 13 statements were acceptable to be included in the final survey questionnaire of the study.

Identified Criteria for Challenges by Expert Participants

There are different challenges to be considered in the adoption of additive manufacturing in small and medium scale enterprises.

A. Economic Factors – The adoption of new technology would be costly based on the resources needed such as software, facilities, and infrastructure. The amount of cost needed to acquire, procure, implement and maintain must be considered by the policy making bodies.
   - The cost needed to acquire, procure, implement, and maintain 3d printers.
   - Cost of Integration
   - Cost of facility improvement and infrastructure
   - Limited budget for research and development

B. Organizational Factors – There will be different challenges that might be encountered in the adoption of new technology. Some might encounter the stakeholder's resistance to change, concern about the loss of productivity during the transition to the new system, and the other challenges. Policy and decision-making bodies must be prepared in order to address these challenges.
   - There is a stakeholders' resistance to change
   - Selecting the employees to be trained
   - Lack of AM personnel/experts within organization

C. Technical/Operational Factors – Challenges in operation and technical factors must also be considered. Challenges such as integration of the new technology in the system, ensuring quality output during integration are some of the factors that decision-makers must consider.
   - Integration in the system
   - Ensuring quality of output during integration

- Identifying appropriate 3D printers to be used
- Concern about loss of productivity during transition to the new system
- Ease of Use

D. External Factor – Challenge in getting support from the government or if there is one, being aware and being able to avail those services is one of the challenges.
   - Awareness of government support

Identified Criteria for the Policy Requirement by Expert Participants

Policymaking bodies must identify the policy requirements for the adoption of additive manufacturing for small and medium scale enterprises. The adoption of additive manufacturing technology requires the implementation of policies which would provide definitive direction and helps in managing risks

a. Training and Development Policy – It is essential to provide a training and development policy for the employees to orient them about the new technology.
   - Training and development policy for the employee

b. Policy to Quality Assurance – The adoption of additive manufacturing technology would require the implementation of Policy for Quality Assurance. There must be a validation of data and information accessed. The system must also allow document authentication.
   - Policy on review and quality check
   - Policy for monitoring the effectiveness of the integration
   - Policy for the integration of new technology into the system/process

c. Policy on Improvement in Facilities and Infrastructure – Integration in the system of new technology requires improvement in facilities and infrastructures.
   - Policy in the improvement/upgrading of infrastructure
   - Policy for facilities improvement

d. Policy for the Assessing the Acquisition of New Technology – Assessing the needs for adoption or acquisition of new technology should be thoroughly studied because the usually the investment is huge, thus, policy should be formulated.
   - Policy for the need assessment for adopting new technology
   - Policy for conducting a feasibility study for adoption of new technology

e. Policy on Safety and Security – Since the acquisition of new technology entails large costs, policy for safety and security must be in placed.
   - Policy for security
   - Policy related to environmental health and safety
   - Disability-related policies for employees

Identified Criteria on Sustainability Factors by Expert Participants

Sustainability factors must be considered by the implementers (top management) if they have enough resources to adopt additive manufacturing.

a. Capability to Implement – Policymaking bodies must assess the capability of the company to adopt additive manufacturing. The cost to be incurred must be determined before the adoption.
   - The cost of adoption of additive manufacturing is affordable
   - Trust that the cost that will be incurred towards the adoption will be sufficient to its effectiveness.

b. Facilities and Infrastructure –Policymaking bodies must determine the readiness of the company in terms of improvement in facilities and infrastructure upon the adoption of technology if it has enough devices, protocols, and procedures for 3D printing operations as well as if there is a repository available for other relevant information.
   - The facilities, devices, protocols, and procedures ready for the adoption of new technology.
   - The 3D printing infrastructure will be properly maintained

c. Training – The availability and capability of the company to provide the necessary training for the adoption of additive manufacturing must also be considered. There must be training, assessment, and updates to the training materials to improve the effectiveness of the training courses offered by the company that would improve the quality of Human Resources.

- Training courses conducted for employees to improve the quality of human resources
- Assessment on the effectiveness of the training courses
- Updates to the training materials of the training courses

d. Integration into the Process – One of the factors to be considered is the capability of the company to integrate the new technology to match the current operational processes. The system must provide modifications without introducing defects or degrading quality. The change process must not unduly disrupt the current management process during the transition from old system to the new one.
   - The new technology will provide modifications without introducing defects or degrading quality.
   - The 3D printing technology can be configurable to match current operational processes.
   - May integrate or import design that are currently in use
   - The change process will not unduly disrupt the current management process during the transition from old manufacturing set-up to the new one.
   - 3D printing may assess and diagnosed for deficiencies of errors

e. Capability to Sustain – It is also essential to determine the capability of the university. Policymaking bodies must determine if they will purchase a system from other vendors or there will be an in-house development based on the skills of their IT support. There must be a continuous research effort to check the integrity, reliability, and effectiveness of the system
   - Will provide empowerment to the stakeholders
   - Protection of the environment
   - The policy making bodies will plan the operational processes towards the adoption of 3D printing
   - There will be continuous research efforts to check the integrity and effectiveness and reliability of the new technology.

Identified Criteria for the Technical Factors by Expert Participants

Based on the results, the criteria for technical factors to the development and implementation of a technology framework for adoption of additive manufacturing in small and medium-scale enterprises are the following:

a. Manpower Skills towards the Adoption - There must be enough manpower who are well-skilled in managing the new technology. It is important to determine the level of skills in a specific department to determine if the company can implement the changes in operation upon the adoption of the said technology.
   - Can operate or use 3D printer
   - Can operate and use solidworks, autocadd, and other 3D software
   - Adopt and learn new technology
   - Attend training that would help to use 3D printer
   - Willingness to use 3D printer
   - Looking forward to use 3D printer soon.
   - Install and configure computer hardware operating systems and applications
   - Support operations for process improvement
   - Check equipment to conduct electrical safety
   - Updated about the latest hardware and software requirements for the needed software for the design
   - Attending information generation, communication, problem identification and help in the process of decision-making.

b. Technical Support - It is a necessity to determine the availability of technical support in the company that will maintain and support the integration in the operations.
   - Specific person (or group) available for assistance with hardware and software difficulties
   - There is a support that will train on the proper usage of the 3d printing
   - Check equipment to conduct electrical safety
   - Diagnosis of hardware and software faults and solve technical and application problems
   - Install and configure computer hardware operating systems and applications
   - Monitor and maintain computer systems and networks

c. Capabilities – It is very important to determine the capabilities of the stakeholders to utilize adopted technology based on their skills.

- Operate or use 3D printer
- Operate and use solidworks, autocadd, and other 3D software
- Install and configure computer hardware operating systems and applications
- Diagnosis of hardware and software faults and solve technical and application problems

d. Willingness to Adopt Additive Manufacturing – One of the factors to be considered in adopting additive manufacturing is to determine the willingness of the end-user to use the technology. In this manner, they must be enthusiastic to apply their knowledge and must be wholeheartedly willing to attend training and seminars to be equipped with the processes involved in the said adoption.
   - Adopt and learn new technology
   - Usage/utilization of technology in work related tasks
   - Enhance effectiveness on the job
   - Willingness to use 3D printer

e. Awareness in Using Additive Manufacturing – Stakeholders must be well-aware about the use of additive manufacturing.
   - Usage/utilization of technology in work related tasks
   - Operate or use 3D printer
   - Operate and use solidworks, autocadd, and other 3D software
   - Adopt and learn new technology

Identified Criteria for the Socioeconomic Factors by Expert Participants

The following are the identified criteria of the socioeconomic factors based on the consensus of the expert participants that must be considered in adopting a additive manufacturing which would provide good benefits for the company if employees were fitted for the job and there is training available for them in utilizing the integration of additive manufacturing in the operations.

a. Cost-reduction - If the adopting additive manufacturing will be implemented properly in the company, it would reduce the operational costs in the production which provides a long-term benefit to the company. There will be an increase in productivity and efficiency which would culminate in profitability and cost savings.
   - Saves much of an operational cost
   - Provides long term benefits to the company
   - Involves short term benefits and in return get long run benefits
   - There will be long term usage of additive manufacturing by the larger community
   - Change initiatives can be easily communicated to the various stakeholders
   - It involves social support network
   - Increase in profit is greater than cost of 3D printer after the integration

b. Process time reduction – The implementation of the adoption of additive manufacturing, it would reduce the time required in the operation.
   - Less material wastage
   - Lesser reworks
   - Lesser time in doing work
   - If any, rework can be minimal

c. Productivity – There will be an improvement in productivity by allowing the employees to concentrate on the more intellectual task at hand since the quality of delivering will be improved through the integration of this new technology. Increases in productivity and efficiency culminate in profitability and cost savings
   - Better quality of output
   - Improves efficiency by assigning tasks according to workload
   - Improving productivity by allowing the employee to concentrate on the more intellectual tasks at hand
   - Facilitate the accomplishment of specified tasks

d. Operations Optimization -The adoption of additive manufacturing would optimize the operations in the company by improving the process.
   - Increases in productivity and efficiency culminate in profitability and cost savings
   - Better quality of output

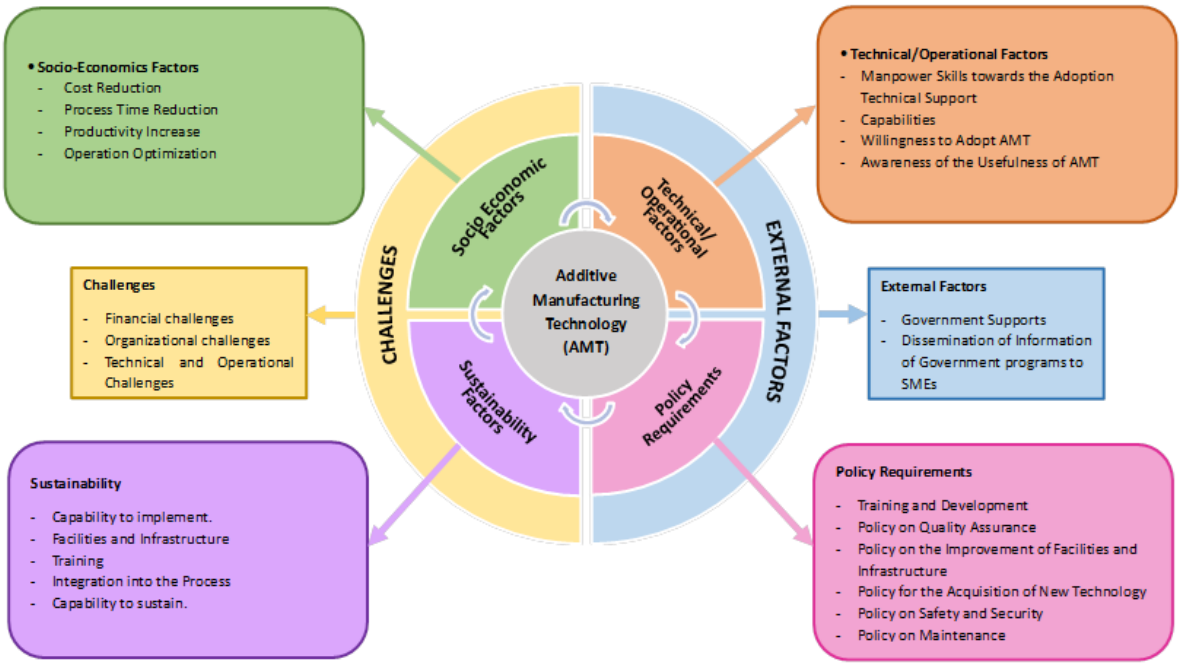

Figure 23: Technology Management Framework for the Adoption of Additive Manufacturing in Small and Medium Scale Enterprises

Based on the results of the study, the following conclusions were drawn:

1. Generally, there is a high level of awareness and readiness of the different stakeholders on the adoption of additive manufacturing technology. It was also established that there is significant difference between the level of awareness and the position of respondents and their nature of business.
2. There is also high level of acceptability of the different stakeholders on the adoption of the said technology. It was also established that there is significant difference between the level of acceptability and the number of years in technology management, in 3D printing, years of operation, and number of employees.
3. Similarly, there is high level of readiness in terms of facilities and infrastructure. It was also seen that there is significant difference between the level of readiness and nature of business.
4. It is important to note also that there is high level of technical viability in the perception of the respondents. There is also significant difference in the perception of technical viability and the position in the company, the educational attainment and the nature of business.
5. There is low level of operational viability based on the perception of the respondents. This is due to their perception that the cost of the equipment and the integration in the operation is too high.
6. Similarly, there is a high level of economic viability based on the perception of the respondents.
7. Overall, the respondents identified financial, organizational, technical and operational, policy requirements, and external factors such as the support from the government are the challenges faced by small and medium-scale enterprises in adopting additive manufacturing.
8. It was observed that the respondents are willing to support the technology adoption. This is due to high level of acceptability of the proposed technology management framework.
9. The respondents perceived that the proposed management framework and roadmap will be effective and viable if there is a support from the top management and the government.

Recommendations

The following recommendations are hereby suggested based on the findings and conclusions of the study.

1. To enhance the stakeholders' level of awareness and readiness for the adoption of additive manufacturing in small and medium-scale enterprises, the following actions should be taken:
   a) It should be integrated into the management's strategy. Integration of additive manufacturing in operations entails changes in the systems. Included in the management strategy are the following:
      i. All stakeholders should be included in the planning.
      ii. Adoption of new technology frequently has an influence on the workforce since many people are hesitant to embrace the change. The success of an adoption can be greatly impacted by delivering technological training and describing the value of additive manufacturing technology for the business and its processes.
      iii. Employ tactics that make these technologies simple to understand and boost worker productivity to encourage your staff to accept this new technology.
   b) Also, DTI and DOST should establish feasible programs for information dissemination and showcase the programs of the agencies regarding additive manufacturing technology. It can be done thru:
      i. Using social media to disseminate information.
      ii. Inviting SMEs to the partner SSF-fabrication laboratory for them to see first-hand the benefits and the ease of use of additive manufacturing technology.
   c) Policies that will improve the awareness of the adoption of AMT should be formulated. Training and development policy and policy for the acquisition of new technology should be given emphasis and should be explained well to the workers and other stakeholders.
2. To improve the readiness of adopting this technology, the company should allocate budget for facility and infrastructure improvements and process integration.
3. To address the issues regarding the adoption of technology, government agencies such as DTI and DOST should provide specific assistance such as financial and management support to all stakeholders regarding technology adoption.
4. To solve the issues in the operation viability, integration of the technology into the operation must be considered.
5. A thorough study such as feasibility study, needs assessments should be conducted to ensure the return of the investment in procuring the said technology.

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