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The Determinants and Business Impact of Additive Manufacturing Technology Adoption: A Case of Ethiopian Metal Manufacturing Industries

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Declaration

I hereby declare that the work being presented in this thesis entitled "The Determinants and Business Impact of Additive Manufacturing Technology Adoption: A Case of Ethiopian Metal Manufacturing Industries" is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis have been duly acknowledged.

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This is to certify that the above declaration made by the candidate is correct to the best of my Knowledge.

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Abstract

Additive Manufacturing (AM) technology, also called 3D-printing, is a disruptive technology providing opportunities and huge potential benefits through innovative way of manufacturing products. This study is concerned with identifying the determinants for adoption of Additive Manufacturing technology within Ethiopian metal manufacturing industries. In light of this objective, the study adopts both quantitative and qualitative approaches with purposive sampling. The quantitative approach used 7-likert scale questionnaire for empirical analysis of the data to determine the factors that influence the adoption of AM technology. For the qualitative approach, an interview is conducted to determine the business impact and the challenges of adopting AM technology. A sample of team leaders, engineers, metal researchers, technicians, IT professionals and quality controllers is taken to capture their opinions, views and reflections about the determinants for adopting AM technology in metal manufacturing industries. A self-administered questionnaire is used to rate the influence of technological, organizational, and environmental determinants on the decision to adopt the technology. Both SPSS and SmartPLS software tools are used for descriptive statistics analysis and structural equation modeling (SEM) of the collected data respectively. Results indicate that out of the determinants, the perceived value, perceived cost, top management support, organizational readiness, external pressure and perceived outside support affecting significantly a decision for adopting AM technology. The study further explores the benefits, potential business impact and the challenges of adopting AM technology in metal manufacturing industries. This study's contribution is to provide academics, business people and policymakers with insightful information about the determinants that influence AM technology adoption and its benefits enabling them to implement the necessary initiatives or policies that are essential for the technology to be adopted successfully. Lastly the study recommends further research in this field.

Key words: *Additive Manufacturing, 3D-Printing, Metal Manufacturing, Technological-Organizational-Environmental Adoption Model*

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List of Acronyms

3D -Three-Dimensional

AI-Artificial Intelligence

AM- Additive Manufacturing

ASTM- American Society for Testing and Materials

CAD-Computer Aided Design

ICT-Information and Communication Technology

IDT- Innovation Diffusion Theory

IoT-Internet of Things

ISO-International Standard Organization

MTIRDC- Manufacturing Technology and Industry Research and Development Center

RBT- Resource-Based Theory

SMEs -Small and Medium Enterprises

STL- Stereo-lithography

TAM - Technology Acceptance Model

TM -Traditional Manufacturing

TOE- Technology-Organization-Environment

CHAPTER 1

1. Introduction

1.1 Background and Justification

Many manufacturing industries are dealing with swift changes in technology, competition from global competitors entering the market, and volatile consumer demand. Organizations that are unable to adapt to the rapidly advancing technologies of today are unlikely to endure. Strategies, processes, and organizational structures must allow an organization to react swiftly and agilely to a rapidly evolving technological environment (Kapoor & Teece, 2021).

Boosting an organization's technological capabilities through technology adoption is the key factor for enhancing business performance. To put in another way, over half of a company's overall productivity growth is achieved by innovating, adopting new technologies and implementing best managerial practices. This makes the company the main creator of value addition in the economy (Cirera et al., 2023).

The technological era known as Industry 4.0, or the fourth industrial revolution, started with mechanical systems and progressed to electrical and digital ones. Currently, smart manufacturing is enabling even greater automation and intelligent system networking (Sony & Naik, 2020).

Additive Manufacturing (AM) technology, also known as 3D-printing, is one of the fourth industrial revolution innovations in advanced manufacturing that has the potential to alter the manufacturing landscape (Kulkarni et al., 2021).

Using three-dimensional (3D) CAD modeling, AM technology facilitates the fabrication of a wide range of simple and complex structures. It is not just used for prototypes, but also for small-scale production due to its many benefits, which include affordable goods, robust and lightweight components, flexible designs, minimal material waste, ease of access, quick design and production, and many more (Bhatia & Sehgal, 2023).

In contrast to traditional manufacturing techniques, AM technology builds objects by layering materials together using 3D model data. Because of this, products with intricate geometry and materials can be produced that are not achievable using traditional production methods (Duvoisin et al., 2018).

The Ethiopian's manufacturing sector is one of the most important economic sectors that play crucial role for the country's economic development and has great potential to significantly increase wealth, create jobs, and reduce poverty. Out of this manufacturing sector, the metal manufacturing and engineering industry accounts for 18 % of the industry sector's GDP after food and beverage sector.

According to the Central Statistical Agency (2018) report, there are 343 medium-and large sized metal manufacturing enterprises in Ethiopia. Out of these, there are 222 manufacturers of fabricated metal products. The remaining are manufacturers of basic iron and steel; machinery and equipment and motor vehicles, trailers, and semi-trailers; which are 76, 31, and 14 in numbers respectively.

According to Gelaye (2018) the three subsectors of the engineering and metals industry—basic metals, structural metal goods, and fabricated metal products—had mean technical inefficiency scores of 0.44, 0.45, and 0.44, respectively, This demonstrates that the technological efficiency of the metal industries is, on average, 55.3%. A contributing factor to low efficiency is the application of outdated fabrication techniques.

This industry is faced with outdated machinery and conventional manufacturing technology making the industry low productive (UNDP, 2023). Conventional manufacturing technology fabricates metal parts involving lengthy processes like cutting, milling, turning, sawing, boring, shearing, die casting which consume more utility, involves more tooling and generates wastage of materials and longer production cycle time resulting in longer lead time of delivering products (Colorado et al., 2023).

Having faced with such conventional manufacturing technology and low productivity, the Ethiopian metal fabrication sector needs to adopt new technology either to complement or replace the existing metal manufacturing technology (Erena et al., 2021).

Replacing the existing metal fabrication process with AM technology process enables the elimination of many limitations of the conventional manufacturing thus enhancing productivity and gaining competitive advantages (Ashima et al., 2021).

Hence to adopt AM technology in Ethiopian metal fabrication industry it is necessary to investigate the determinants that are important for adopting the technology and to assess the business impact and the challenges it brings.

1.2 Problem Statement

Under GTP (2010-2015), the Ethiopian government has formulated policies to adopt new technologies that can accelerate the growth and productivity of the metal manufacturing industry, and replace imports of parts and components that create market gaps and demand high foreign currency with local manufactured products.

Though fabricating locally these parts or components has been the main goal and policy of the government through adopting of new manufacturing technology, Ethiopia is still lagging behind other economies in adopting new technologies (Cirera et al., 2023).

Moreover there is lack of awareness that are faced by the firms, including gap in the knowledge about new technologies, or flawed beliefs that might result in managers believing that they already use the most advanced technologies available (Cirera et al., 2023).

Due to lack of embracing innovation, many metal manufacturing industries in Ethiopia are still dominated by conventional manufacturing technologies for long period of time. This condition exposed them to the following challenges

1. They are unable to manufacture complex and intricate parts as per the customer demand
2. They are faced with low productivity in their operation
3. Existing manufacturing process is not flexible

These challenges make the Ethiopia metal manufacturing industries less efficient and effective in their operation leading to less competitiveness to the foreign competitors.

Therefore adopting AM technology is essential in order to make the industry more efficient, effective and competitive in the market. Even though there are many literatures written about the advantages of AM technology, there are no studies made regarding its adoption and importance of AM technology for metal manufacturing industries development in Ethiopia

Therefore this study seeks to explore the adoption determinants and investigate the business impact and the challenges of adopting AM technology within the Ethiopian metal manufacturing industries.

1.3 Research Questions

After completion of this research, the questions that are answered include the following

1. What are the determinants that influence the adoption of AM technology?
2. How does adopting AM technology affect business performance in the manufacturing system?
3. What are the challenges of adopting AM technology?

1.4 General Objectives

The general objective of this research is to investigate the determinants that influence the adoption of AM technology in Ethiopian metal manufacturing industry.

Specific Objectives

The specific objectives are:

1. To investigate the determinants that influence the adoption of AM technology in Ethiopian metal manufacturing industries
2. To assess the business impact of adopting AM technology in metal manufacturing system
3. To identify the challenges of adopting AM technology in metal manufacturing system

1.5 Scope of the Study

The study main focus is to explore the determinants that are important for adoption of AM technology within the Ethiopian metal fabrication industries. Besides it assesses the potential business impacts to be brought by adopting AM technology. The last focus is to identify potential challenges in adopting the technology.

1.6 Significance of the Study

After completion of this research, its significances are:

1. It will provide valuable insights about the determinants that affect AM technology adoption in Ethiopia
2. It will show the potential business impacts and challenges of AM technology if it is adopted in Ethiopia
3. It will show the importance of adopting AM not only attractive for prototype production but also for commercial and industrial purposes.
4. It aims to contribute to the efforts by academicians, executives and policymakers who want to transform the traditional manufacturing into AM based processes
5. Generally it will create awareness about the importance of embracing AM technology not only for business operations but also for economic growth of the country.

1.7 Organization of the Study

This research is organized into five chapters.

Chapter 1. Outlines the study's introduction and provides background information, justification and research problem of the study. It also addresses the research questions to be answered, the research objectives to be achieved, the significance and the scope of the study.

Chapter 2. Focuses on reviewing a range of relevant material, including books, journals, and articles. In order to develop the conceptual framework and research hypotheses, it also discusses the theoretical perspective and relevant empirical studies that constitute the basis of the study.

Chapter 3. Describes the methods used for data collection and analysis, sample selection, research design, and sampling techniques.

Chapter 4. Records the outcomes of the data analysis and discussions

Chapter 5. Summarizes the study's general conclusion and offers recommendations.

1.8 Limitations of the Study

There are shortcomings in data collection due to human constraints in the target population. One shortcoming may be different levels of understanding about AM technology among participants during data collection, so the reliability of the data could be affected. Also some relevant people to the study did not have sufficient time to be involved in the interview or filling the questionnaire. So the size of the collected sample is not as expected.

CHAPTER 2

2. Literature Review

2.1 Introduction

Companies should evaluate their value chain management and respond fast to the rapidly changing technology environment in order to stay competitive. Any technology has lifecycle and for this they need technology adoption strategy in their plan.

The foundational components of strategic technology management are innovation and technology (Sonar et al., 2020). Before being adopted, new technology's capabilities and qualities must be assessed throughout the organization. Technology should be linked to and in line with the business strategy, taking into account the significance of new technology and its relationship to the firms' overall competitive strategy. Furthermore, throughout the value chain process, businesses must develop their raw material, product, service, and process strategies in light of new technologies (Singhal et al., 2020).

Adoption of technology has become crucial in the modern era for formulating business strategy and sustain competitive advantage. In every field and business, technology adoption management is critical. It applies not only to product-based industries but also to service-based industries. Therefore, effective management of technology adoption will give businesses a competitive edge over their rivals (Kapoor & Teece, 2021).

Adoption of technology should be used to alter short competitive advantages that can be leveraged to develop long-term competitive advantage. A firm needs to continuously scan, search, and explore local and distant markets as well as technologies (Kapoor & Teece, 2021).

In fact, businesses that are adept at identifying and seizing new product innovation prospects will be able to safeguard their intangible assets and maintain their high level of performance. Businesses can obtain a competitive edge over their rivals by breaking down the technology adoption process into three separate capabilities: (1) identifying new technologies and market opportunities; (2) seizing those opportunities; and (3) being able to realign available assets to capitalize on those opportunities (Balakrishnan et al., 2021).

2.2 Technology Adoption Process

Technology adoption process involves many stages. Achieving successful adoption and implementation of technology requires a thorough examination of the processes involved in user acceptance and adoption. Many researchers have indicated different types of adoption process stages from different perspectives.

According to Rogers (2003) adopting an innovation involves an organization's members evaluating its possible advantages and risks in light of the technology they have learned about. Three categories of innovation knowledge are crucial in this process because they help potential adopters go from ignorance to awareness or knowledge, attitude formation or persuasion, adoption decision, evaluation and execution, and confirmation of the decision. Zaltman et al. (1973) separated the adoption process into six phases: decision-making, acquiring knowledge, forming attitudes, initial implementation, and sustained implementation to bolster this argument. According to Damanpour & Schneider (2006) pre-adoption, adoption decision, and post-adoption are the three primary phases of technology adoption in businesses. These phases are sometimes referred to as initiation, adoption decision, and implementation. Assuming the innovation adoption process in terms of assimilation, other researchers have defined an adoption process that includes awareness, interest, evaluation, commitment, limited deployment, partial deployment, and general deployment (Hameed et al., 2012). On the other hand, other studies contended that a sequence of actions, encompassing initiation and progression to adoption, adaptation and knowledge management, characterizes the phases of the adoption process (Bolatan et al., 2022). Furthermore, Zhu et al. (2006) in their study on technology diffusion perspectives in e-business, characterize the stages of innovation assimilation as initiation, adoption, and routization. Gallivan (2001), however, identified three separate stages of assimilation: (a) the primary authority's adoption decision; (b) organizational assimilation and secondary adoption processes; and (c) organizational acceptance and consequences. Salim (2014) uses five common phases to make the different approaches to the adoption process more broadly applicable. These include: (1) awareness / need identification / knowledge, (2) interest / information search / product brokering, (3) evaluation / selection / negotiation, (4) trial / choice / decision, and (5) commitment / purchase / implementation / adoption. The entire technology adoption process can be represented by five stages, specifically: awareness, interest, evaluation, trial, and adoption (Rogers, 2003).

Early research on innovation mostly focused on individual behavior, but more recent studies describe adoption from a variety of angles at three different levels of analysis: individual, group, and organizational. Research conducted at the organizational level focuses on how innovation adoption affects an organization's overall performance (Slappendel, 1996). To create a model that represents the process of IT adoption in businesses, Hameed et al. (2012) took into consideration three levels of analysis. These levels are as follows: individual level analysis, which assesses usability and practical application of innovation; examination at the organizational level, which looks at organizational characteristics in attempting to learn about innovation until the point of technology acquisition; and interactive process perspective, which takes into account the relationships between individuals and the organization during the adoption process.

Damanpour & Schneider (2006) suggest three categories of innovation knowledge that are crucial for assisting prospective adopters in overcoming their "ignorance" through awareness, attitude formation, and evaluation are based on information acquired during the pre-adoption process.

1. Awareness: being conscious that an innovation exists and its main characteristics.
2. How to be knowledgeable: the understanding required to make the best use of an innovation.
3. Knowledgeable principles: information pertaining to the operational concepts that underpin the innovation's functionality.

When it comes to individual technology adoption, the above definitions of innovation knowledge may be straightforward and consistent, but when applied to organizational settings where the process is intricate and complex, they become ambiguous (Kyratsis et al., 2012).

2.3 Technology Adoption Levels

The technology adoption levels are well illustrated by Roger's diffusion of innovation theory. This theory's central claim is that a new idea's ability to spread depends on four factors: innovation, communication channels, time, and social structure. The process of diffusion consists of five stages, namely, knowledge, persuasion, decision, implementation, and confirmation as shown in Figure 1.

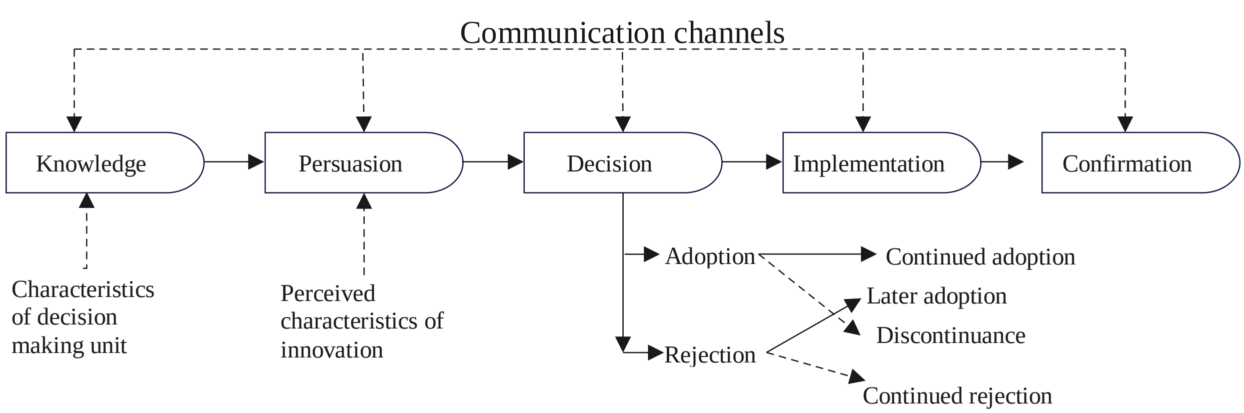

Figure 1 Process of Diffusion of Innovation (Rogers, 1995)

According to this theory, there are five categories of technology adopters: innovators, early adopters, early majority, late majority and laggards

<u>Innovators:</u> are the initial users of a new technology. This stage is associated with a high level of uncertainty for two reasons. First of all, the technology is still in its experimental phase, and secondly adopters might not fully understand how to incorporate the new technology into their current setup. In general, innovators have a strong financial position and a high tolerance for risk. It is true that those who adopt technology earlier are seen as more inventive than those who adopt technology later because they have no one to follow.

<u>Early Adopters</u>: Even though they don't take as many risks as innovators do, early adopters nevertheless have to deal with a lot of uncertainty. Although the technology is no longer in the experimental stage, technological maturity has not yet been attained. Early adopters have typically had the opportunity to watch and absorb the successes and setbacks of innovators. They can use this knowledge to lower the risk involved in implementing the new technology and raise he likelihood of the business's successful integration.

<u>Early Majority:</u> Early Majority enters the adoption process when the advantages of adoption are still quite substantial and the risks have been reduced. The above groups' together account for about 50 % of all potential adopters

<u>Late Majority:</u> Late Majority represents adopters who purchase the new technology due to intense pressure from competitors. In terms of business, this indicates that the late majority adopters have already recognized that investing in the new technology is beneficial because their competitors have gained a competitive edge.

<u>Laggards:</u> Laggards are the ones who adopt last for a variety of reasons. They may simply be resistant to new technologies or the technology may have a tangential role for them in their operations, or they have very conservative thought and behavior patterns. Both late majority and laggards hold the remaining 50% of all adopters.

To summarize, considering the literature on the phases of the process of adopting innovations, there are many approaches or views illustrated by different researchers. However, the stages of pre-adoption, adoption-decision, and post-adoption are roughly used where these perspectives on adoption phases fall. Therefore, the adoption process of AM technology is examined in this study using three stages: pre-adoption, adoption-decision, and implementation (post-adoption).

The beginning (pre-adoption) phase entails actions pertaining to identifying a need, gaining awareness or knowledge, developing a perspective on the innovation, and putting forth the innovation for adoption (Rogers, 1995; Damanpour & Schneider, 2006). The adoption-decision stage represents the choice to embrace the idea and assesses the suggested concepts from a technical, economical, and strategic standpoint together with allocating resources for its acquisition and execution. The post-adoption implementation stage involves preparing the organization to use the innovation, conducting a trial to confirm user acceptance, and continuing to use the innovation (Rogers, 1995).

2.4 Determinants for Technology Adoption

This study seeks to identify determinants for adoption of new technology based on theoretical foundation. There are many technology adoption theories and frameworks proposed by different researchers and applied accordingly according to the need and context of an organization. This study considers three theories for adopting new technology on organizational level as they are widely used by many scholars in technology adoption studies (Hameed et al., 2012) and described as follows.

2.4.1 Rogers' Innovation Diffusion Theory (IDT)

This theory is essential to understanding the technological aspects that affect the choice to adopt an innovation. According to Rogers (2003), the innovation attributes have a significant impact on the decision to adopt a particular technology, and there are five key characteristics that should be taken into account when examining a particular technology adoption as shown in Figure 2. Those five characteristics are:

1) Relative advantage 2) Compatibility 3) Complexity 4) Trialability and 5) Observability

Rogers (2003) defines relative advantage as the perceived improvement of an innovation over its predecessor. This can often be measured in terms of profitability. However, the type of relative advantage an adopter experiences is influenced by the innovation's characteristics and the adopter's attributes. Therefore, those adopting new technology seek information to reduce uncertainty about the relative advantage it offers. In essence, if a technology provides a relative advantage, it is more likely to be adopted. The components of relative advantage typically include economic benefits, reduced production costs, lower initial costs, shorter lead times, and rewards (Rogers, 2003). Consequently, adopters of novel technologies are thus motivated to seek out information that will reduce ambiguity regarding the innovation's relative advantage. To put it simply, technology innovations are more likely to be adopted if they provide a relative advantage to the business (Saghafian et al., 2021).

The second attribute of the innovation is its compatibility. Compatibility is a term used by researchers to describe how closely an innovation aligns with the adopters' values, past experiences, and needs. In that case, ideas that mesh better together are more likely to be implemented. That also suggests, though, that an idea might or might not be compatible with the values of the innovation context, previous concepts, and client needs. Strong connections to previous ideas make a technological innovation more acceptable and hasten its rate of adoption (Oliveira & Martins, 2011). In this case, if the adopter readily accepts the new ideas based on the prior ideas that he or she is already familiar with, the previous technologies can be used as a tool for evaluating the new ones.

However, some researchers contend that adopters cannot classify a new technology as innovative if it is fully compatible with earlier innovations because it does not signify a substantial change. When technology does not align with consumer needs, expectations, or beliefs, the same response takes place (Rogers, 2003). Because of this, it is crucial for small and medium enterprises (SMEs) to make sure that any changes in the way they adopt technology are in line with their needs, values, and organizational structure. According to Rogers (2003), an innovation's compatibility can be measured by how well it satisfies the needs that customers have identified. However, customers might not always be aware of the needs connected to a particular innovation. Consequently, businesses should aim to create needs to the extent that customers view those newly created needs favorably.

Complexity is the third feature of the innovation. Complexity, according to Rogers (2003), is the degree to which an invention is perceived as being relatively challenging to comprehend and implement. In this case, the degree of uncertainty surrounding the success of an innovation's implementation rises due to the complexity of technology. As a result, there is a greater risk of innovation adoption (Saghafian et al., 2021). It has been discovered that this factor negatively affects the adoption of a certain technology, especially by SMEs.

The trialability of innovation is its fourth quality. Trialability, according to Rogers (2003), is the degree to which a new idea can be tested in a limited way. Thus, technological innovations with a high degree of trialability are more likely to be adopted because they allow users to test the technology before it is widely used (Saghafian et al., 2021). Stated differently, new ideas that are easily divided for trial activities are quickly adopted. Those who adopt early are more likely than those who adopt later to understand the value of trialability.

Observability is the fifth innovation characteristic. According to Rogers (2003) the degree to which the outcomes of an innovation are apparent to other people is known as observability. Some innovations are simple to watch and explain, while others are more challenging. In the context of SMEs, the likelihood of a technological innovation being adopted increases with the innovation's observability (Saghafian et al., 2021).

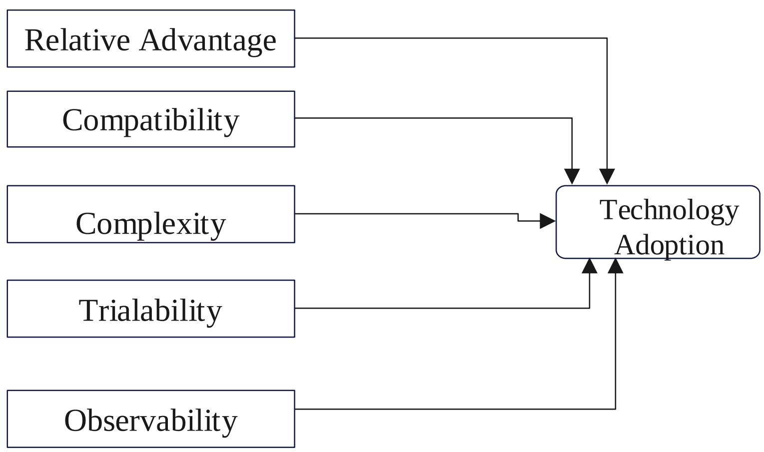

Figure 2 Diffusion of Innovation Theory (Rogers, 2003)

2.4.2 <u>Technology Acceptance Model (TAM)</u>

The Technology Acceptance Model (TAM) gained attention in the 1970s as technology was developing rapidly and scientists were interested to predict which technology would be adopted by which organizations. For this reason, Davis (1989) created the simplest version of TAM for the conceptual model of technology acceptance, breaking the model down into three main sections:

1) Stimulus: the system's attributes and powers; 2) Organism: the rationale for the user's choice to employ this particular system; and 3) Response: the system's actual use (Davis, 1989).

Studies on technology adoption have used the TAM extensively. The strength of the model lies in its simplicity; it only includes two constructs, "perceived usefulness" and "perceived ease of use," which enable it to predict the degree to which new technologies are adopted at the individual level (Momani & Jamous 2017).

According to TAM, perceived ease of use affects perceived usefulness as well as attitudes toward adopting new technology. Ease of use is associated with perceived benefits, so people tend to view recently adopted systems as more beneficial (Lai, 2017).

Originally designed to forecast users' adoption of new technology, TAM is now anticipated to clarify and forecast future employee behavior, and its relevance in post-adoption surveys has been confirmed. Moreover to differentiate between principles, attitudes, beliefs, and intentions, it used the theory of reasoned action (TRA) and theory of planned behavior (TPB) (Dube et al., 2020).

Thus, it can be said that the TAM model includes explicit implications that are drawn from both theoretical and practical viewpoints regarding the adoption of technology. As a result, as the TAM has developed, numerous studies on perceived system usefulness and ease of use have been carried out (Momani & Jamous, 2017).

A meta-analysis of these studies by Tornatzky and Klein (1982) revealed a strong correlation between the innovation's features and adoption. More precisely, the complexity of the innovation or technology adopted is the most significant factor influencing the relationship between the type of innovation and its adoption (Dube et al., 2020).

According to Davis (1989) conclusion, people decide whether or not to accept a system based on how much it would improve their ability to do their jobs as well as their perceptions of how adopting a given system will influence system usage behavior. Put differently, the TAM model indicates that the ultimate adoption behavior is contingent upon the adopter's perception of the technology's usefulness and ease of use. These two elements are critical because they shape the adopter's behavioral intention, which determines whether technology is accepted or rejected (Momani & Jamous, 2017).

The use of TAM solely for forecasting voluntary system technology adoption is one of the most contentious limitations since voluntary adoption is practically always chosen despite the many examples of companies forcing their staff to use/adopt a particular system without providing them with an option (Lai, 2017).

Despite the wide range of studies and research conducted on TAM, this model has certain limitations of its own. Williams et al. (2009) highlighted the need for key components to be identified and incorporated into the models because empirical research using TAM do not always yield absolute steady or strong results. This demonstrates the necessity of integrating the TAM model with other theories and their models of adoption.

There have also been several discussions over the relative importance of perceived system usefulness and perceived ease of use in relation to adoption behavior, as well as the possibility of additional external factors influencing adoption behavior. In addition to the perceived usefulness and ease of use of the system, the adoption of a specific system technology can be directly influenced by a number of external factors, including the user's age, prior experience with similar system usage, technological knowledge, and related education (Sharma & Mishra, 2014). Therefore, the final TAM version identifies that some external variables also have an impact on the adopter's decision to accept a particular technology and should be included in the model. These variables include system characteristics, user training, and user participation in the design and implementation process in addition to the perceived system usefulness and ease of use of the technology that needs to be adopted (Lai, 2017) (Figure 3)

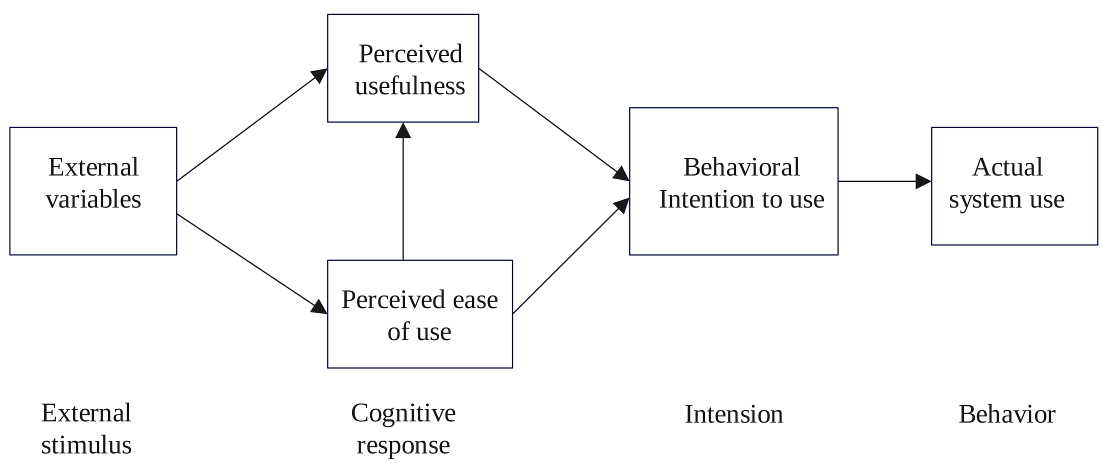

Figure 3 Final version of Technology Acceptance Model (Davis & Venkatesh, 1996)

2.4.3 <u>Technological, Organizational and Environmental Framework (TOE)</u>

The aforementioned innovation attributes were examined within a technological framework as factors that impact an innovation's adoption. However, the organizational and environmental contexts are not considered when analyzing the factors that impact the adoption of innovations (Ukobitz , 2020).

The Tornatzky & Fleischer (1990) framework, known as the Technology-Organization-Environment (TOE) framework, provides a theoretical foundation for understanding the factors that influence technology adoption from three key contexts: technology, organization, and environment (Emon, 2023).The TOE is consistent with Roger's Innovation Diffusion Theory (IDT) (Awa et al., 2017). Because TOE includes technological, organizational and environmental factors, it performed better than other models used to examine the adoption, use, and creation of value from technology (Dube et al., 2020). In addition, it provides a comprehensive picture of how users adopt technology, how that adoption is carried out, what challenges to expect, how that adoption affects value chain operations, how that adoption is disseminated among businesses, what influences business innovation adoption decisions, and how to improve organizational capabilities through the use of technology (Dube et al., 2020).

According to TOE framework (Tornatzky & Fleischer, 1990), these three TOE framework contexts are explained as follows.

Technological: The features of the technologies that an organization can adopt as well as its current level of technological maturity are related to the technological context of that organization. Consequently, the latter-mentioned variables from Roger's (IDT) provide the foundation for the technological context of the TOE framework (Angeles, 2014). Furthermore, Angeles (2014) suggests that the technological context encompasses the elements that affect how an individual, an organization, and a business adopt innovations.

The adoption decision is influenced by the adopter's perception of the technological innovation for the organization, which is determined by the benefits of the technology as witnessed by the experiences of already existent adopters. As the adopter evaluates how well the technology will work with the organizational values and strategic goals, technological compatibility is important in this situation. Finally, adopters' perceptions of how easy it is to deploy technological innovations are influenced by the complexity and flexibility of the technology (Awa et al., 2017).

The technological context of the TOE framework is primarily based on the Technology Acceptance Model (TAM) and Roger's Innovation Diffusion Theory (IDT), as the adoption decision is influenced by the perceived usefulness and ease of use of the adopted technology. Nonetheless, other research finds that observability is irrelevant and that system complexity, integration, standardization, perceived intended benefits and perceived unintended benefits, are significant factors for adoption (Musawa & Wahab, 2012).

Organizational: The TOE framework examines how internal factors within an organization affect the process of adopting new technology. The term "organizational context" refers especially to concise measures relating to a company, such as its scope, size and executives' guiding principles (Dube et al., 2020). The company's top management is best suited to start and oversee the planning and communication phases of the technology adoption process. Since they are able to convey the company's mission, core values, and the technology significance in achieving the corporate plan, senior managers are viewed as the main forces behind organizational changes. Moreover, senior executives possess the ability to identify and convey the significance of technological innovation both within and beyond the organization. Stated differently, senior leadership is essential in promoting the use of technology and its support has a favorable impact on the company's choice to implement a new technology (Awa et al., 2017).

Furthermore, teams are formed by top management to plan and envision the significance of an innovation. The organizational structure and the caliber of human resources play a crucial role in the success of the technology adoption process. Stated differently, there exists a correlation between specific organizational structure changes and the company's organizational readiness and the eventual employment of skilled labor resources for the effective implementation of the adopted technological innovation (Angeles, 2014).Therefore, it is essential to have relevant prior technological experience in order to avoid the need for significant structural changes.

Apart from the aforementioned intrinsic factors, the size of the organization also holds significant influence in the process of embracing new technologies. In this context, it is believed that larger organizations possess the necessary human resources and free disposable capital to facilitate the adoption of new technologies more easily than smaller ones and TOE, suggest that larger businesses are better equipped to take advantage of cutting-edge technologies (Awa et al., 2017). However, the organizational size variable is extremely contradictory, since some researches indicate that small businesses are more flexible in implementing new technologies.

Environmental: Lastly, a number of external factors influencing the adoption process of new technologies are identified by the TOE framework. These external factors are examined in light of the environment, which is characterized as the assortment of various elements surrounding the enterprise and influencing the uptake of new technologies (Angeles, 2014). The environmental context focuses on the areas where a business manages its operations, with consideration for external factors that may have an impact on the enterprise, such as competitors' market size, outside support, governmental regulations, incentives and policies (Dube et al., 2020). Dube et al. (2020) further add other elements to the external factors namely the characteristics of the industry, rivalry, connections with vendors and clients, and the stages of the technology's life cycle.

Oliveira & Martins (2011) contend that the factors within the three contexts of the TOE framework that impact the adoption of an innovation can vary depending on the technology, industry, country, and specific study. For example, Gutierrez et al. (2015), found trading partner or supplier pressure as the most significant factor in their study of the adoption decision of cloud computing technology within the frame work of TOE. On other hand, Lin et al. (2022) found in their study of the use of AM technology in mass customization, the most significant factors influencing adoption to be equipment cost, followed by production efficiency, material limitations, quality requirements, and technological level.

Different researchers have used one or more adoption theories in their empirical studies for determining factors for technology adoption. Here are some studies.

Handfield et al. (2022) used the five attributes of Roger’s IDT that influence the pace at which AM technology is adopted in light of business objectives, to evaluate a collection of seven case studies for the successful of AM technology adoption. In addition to the above attributes, Oettmeier & Hofmann (2017) used the factors absorption capacity, perceived outside support and external pressure in their study of supply chain related determinants for AM adoption.

Sobota et al. (2021) has classified enabling factors found from other studies based on four perspectives: These are technological, supply, demand and market aspects.

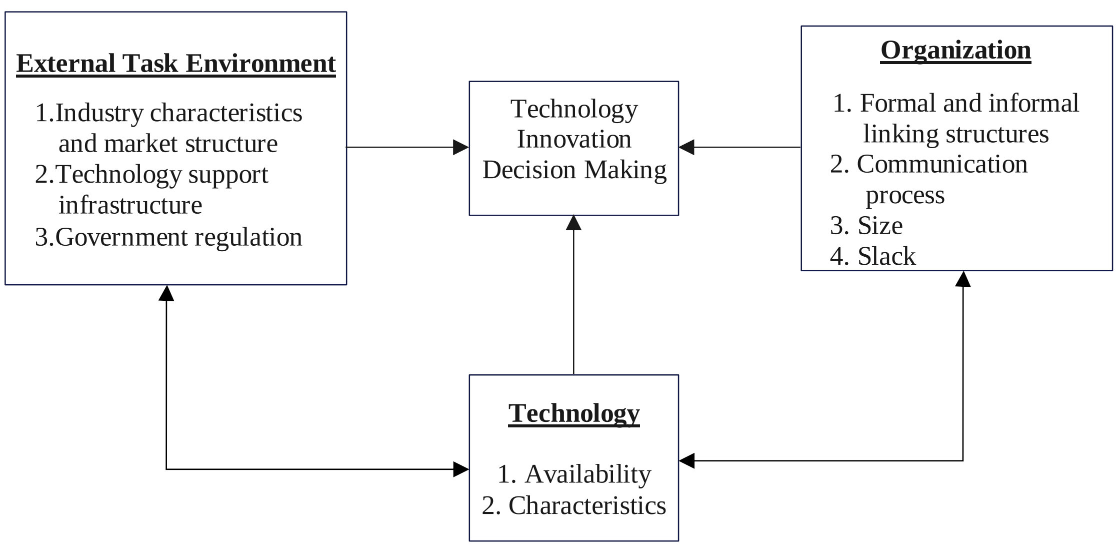

Figure 4 TOE adoption framework (Tornatzky & Fleischer, 1990)

Darbanhosseiniamirkhiz & Wan Ismail (2012) proposed in their study a framework based on TOE framework that synthesized previous studies and this framework consists ten (10) adoption factors, categorized in three contexts, which affect small and medium-sized enterprises' (SMEs) adoption of advanced manufacturing technologies. The contexts are:

1) Environmental (Financial resources, supplier support, and external pressure)
2) Organizational (Top management commitment, manufacturing strategy, organizational structure and culture, and human resource practices) and
3) Technological (Perceived benefits and utilized technologies)

In summary, a variety of viewpoints are covered in the above discussion of technology adoption models and theories based on the literature review. The review discusses the various theories of technology adoption, each with its own theoretical underpinnings, variables and constraints. The adoption factors are related to each other to some extent and most of them are used for the empirical analysis of this research. Also the study considers other adoption factors based on the organizational and environmental contexts on which the study is carried out.

2.5 Impact of Technology Adoption on Business Performance

Businesses aim for technological innovation as well as a competitive advantage that sets them apart from rivals by developing highly customized, inventive products that provide customers with a special value (Singhal et al., 2020).

Therefore this topic considers two competitive theories that help explain how organization can have competitive advantage over its competitors in the market by enhancing its internal capability through adopting new technology in addition to having other resource capabilities. The theories are resource-based theory (RBT) and the theory of dynamic capabilities. The variety of resources and capabilities within a population of firms, which determines the competitive advantage of each firm, is one of the core concepts of RBT. The idea of resource heterogeneity makes the assumption that a business with distinctive resources in a given circumstance can potentially be better equipped to perform certain activities and enhance competitiveness and these resources can originate from a variety of sources, both inside and outside the firm (Barney et al., 2021).

According to Kozlenkova et al. (2014) internal resources include things like brand management, low-cost processes, logistics, and R&D capabilities, while external resources are for instance can be customer demand and technology adoption.

According to RBT, a company can achieve a number of benefits from adopting new technology, including lower production costs, shorter lead times or production processes, quicker machine setup times, lower energy and labor costs, and better utilization of raw materials-all of which are indicators of increased operational efficiency and gaining competitiveness (Singhal et al., 2020).

Efficiency refers to the highest feasible output (least possible input) utilizing a specific set of inputs (outputs), and it measures the distance between a company's production position and the production frontier. This means, the efficiency of each firm can be quantified as its distance from the best practice frontier, which is a relative definition of productivity (Hwang and Kim, 2022).

Hwang and Kim (2022) have shown in their study to compare the technical efficiency of the production processes of small and medium-sized enterprises (SMEs) that have incorporated emerging technologies to those that have not. Their empirical findings showed that adopters' technical efficiency was higher by more than 26% to that of non-adopters after controlling both observed and unobserved factors. Even though the majority of earlier researches focused on ICT adoption regarding efficiency, they justify the existence of positive correlation between productivity and technology adoption.

Firm competitiveness which is the company's ability to consistently outperform its competitors in the market by providing goods and services that meet customer needs, has been gaining more attention due to its strong correlation with innovation (Sonar et al., 2020).One of the most significant problems facing modern manufacturing companies is the pressure from competitors to achieve operational excellence and, as a result, increase their market share both domestically and internationally (Hwang & Kim, 2022).

One new strategy to increase a company's competitiveness is to embrace innovative manufacturing technologies and compete through operational excellence which proves the positive correlation between advanced manufacturing technology and business competitiveness (Sonar et al., 2020).

Dynamic capabilities are based on two classical strategy theories - resource-based theory (RBT) and market positioning. Furthermore, the more capable a firm is of identifying new technology, new markets, resources, and combination opportunities, the more likely it is to compete with others in those areas (Collis et al., 2021).

An effective use of technology can give businesses a competitive edge over rivals by giving them a flexible approach for attracting clients and fending off threats from the market. Since the adoption of technology and dynamic capability are correlated, controlling the adoption of technology will raise the firms' level of competency. This is accomplished through dynamic capability, which is intended to generate wealth for businesses operating in fast-paced technological environments with the goal of maintaining competitive advantage through shifting the resource base (Collis et al., 2021).

2.6 Additive Manufacturing (AM) Technology

The ISO/ASTM (2021) describes additive manufacturing (AM) technology as the process of combining materials, typically layer by layer, to create objects from 3D model data.

The term additive manufacturing (AM) refers to a process of blending materials, such as powders and liquid resin, via binding, fusing, or solidification and constructs parts layer by layer with 3D CAD modeling. Moreover AM processes can be referred to by terms like 3D printing, solid free form fabrication, rapid prototyping, direct digital manufacturing, and rapid manufacturing (Abdulhameed et al., 2019).

The following process chain is typically followed when AM technology is producing final, useable parts or components. It always needs an appropriate 3D model, a product designer (for the design's functionality), and an AM specialist, for product design optimization. This is different from traditional or subtractive manufacturing where a digital model is no longer necessary. The traditional processes are used where parts are fabricated from initial raw material object by reducing its size through many processes to the final product (Martinsuo & Luomaranta, 2018).

AM requires specialized equipment, raw materials (often powdered metals), and personnel with the necessary skills and training to operate the equipment. The parts can undergo post-processing and quality control after manufacturing before being used as an end product or put together as a part of another product (Murmura & Bravi, 2018).

As illustrated in Figure 5, an AM process primarily consists of three phases: design, processing, and testing.

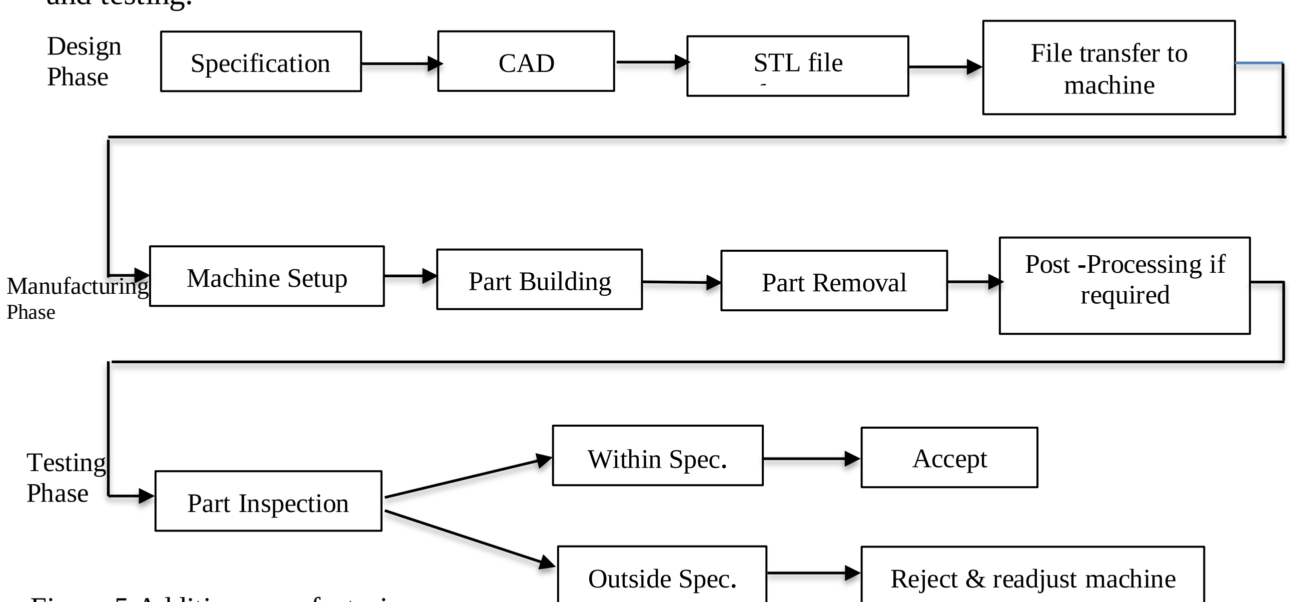

Figure 5 Additive manufacturing process

To summarize the subtractive or traditional manufacturing (TM) technology involves cutting, turning, boring, sawing, milling and other tasks in order to produce one final work piece out of one raw material object. This process uses more machine accessories, tooling and energy and generates wastes whereas the AM technology is completely different in that it produces parts from powdered materials by forming layer upon layer on one machine avoiding the need for more tooling, accessories, energy and no wastage at all.

2.7 AM Technology Benefits

AM is a novel and innovative manufacturing process that has captured the interest of numerous industrial researchers in the recent years due to its potential effects on businesses (Gibson, 2017). Thin layers of material can be used to construct intricate geometries that are unattainable through traditional manufacturing methods like casting, forging, and machining. This allows the manufacturing sector to create any kind of fancy element, giving designers the power of veto (Abdulhameed et al., 2019).

Researchers emphasize that AM technology is regarded as a crucial manufacturing technology for the future sustainable society and offers various potential benefits for sustainability (Niaki et al., 2019).From the economic sustainability perspective, AM allows less resource usage and lower operational costs. Regarding environmental sustainability, AM reduces emissions and uses less energy. From social sustainability perspective AM offers a number of positive social impacts, especially, how consumers use products and businesses meet demand (Eyers et al., 2021).

AM technology has the ability to significantly alter and disrupt businesses in ways that go beyond their internal operations. The technology can be used for simple on-demand production and manufacturing in remote areas close to the customer minimizing the supply chain process. It may change how customer’s role is viewed, how the supply chain is organized, and how market-oriented strategies are used to run and manage the supply chain (Handfield et al., 2022).

By using decentralized products close to customers, AM enables mass customization and individualization of products (Niaki et al., 2019).

According to Niaki et al., (2019) by improving process efficiency, lowering raw material costs, eliminating several manufacturing steps, AM process can optimize entirely the value chain.

Regarding product development, AM is a solution that is deliberately used to accelerate the prototyping process. This offers the chance to circumvent the expenses and effort linked to a formal tooling phase. Two important performance indicators in this context are design flexibility and development speed, which help justify AM adoption (Chan et al., 2018). Prototyping products with faster manufacturing cycle time and low customization costs are AM’s perceived advantages (Baumers et al., 2017).

Speedy replenishment of parts is regarded as being more important than part costs (e.g., in aviation applications). In this case, AM helps reduce inventory costs related to conventional methods of keeping spare parts on hand in case of low demand. For example, spare parts for old cars might be needed and they cannot be found easily in the market but AM can make them on demand (Handfield et al., 2022).

For certain low-volume products, AM is currently considered a competitive alternative to conventional manufacturing process options (Eyers et al., 2021). To satisfy their customers, small-to-medium-sized businesses that produce a wide range of customized goods in small quantities need to find a balance between operational efficiency and novelty and innovation. Even though AM technology is still not competitive for production at medium and high volumes, it can be useful for smaller volumes due to its ability to provide shortened lead times and occasionally reduced production costs overall (Achillas et al., 2017). This is true in medical transplant centers where patients need specialized products made quickly and at high cost for their surgical operations (Handfield et al., 2022).

With AM technology, it could be feasible to create non-standard design objects that would be difficult or impossible to create with conventional methods (Eyers et al., 2021). Some authors highlight the revolutionary shifts that additive manufacturing brings to the manufacturing process by quickly customizing intricate parts to meet the demands of clients. This includes conformance quality standards and enhanced performance through optimized design and personalized made-to-order items that increase product range flexibility (Handfield et al., 2022).

Numerous studies have shown how AM technologies can be used in the fields of tissue scaffolds, biomedical implants, automotive spare parts, aerospace, and jewelry (Niaki et al., 2019; Gibson, 2017). Furthermore, based on CAD data, additive manufacturing (AM) may now be utilized to create metallic, ceramic, polymeric, and biological parts in a matter of hours thanks to technological breakthroughs and the rapid industrialization growth. Today's commercial AM technology comes in a variety of forms and are used to manufacturing and assembly concepts in product design (Sonar et al., 2020).

According to several writers who have examined the advantages of implementing AM, AM can create opportunities for changes in warehouse management and inventory policies of supply chain (Attaran, 2017; Oettmeier & Hofmann, 2017). According to Attaran (2017) the major benefits to be gained from AM are impact, cost, speed, quality, innovation, and transformation. Attaran (2017) further predicted savings in production cost as the production cost is reducing and speed is increasing for metal AM technology for the next 5 years as shown in Figure 6

To summarize, as it can be seen from the above, as an emerging manufacturing technology, AM technology has transformed the manufacturing industries landscape and markets to an incredible degree due to its adoption. This technology is being adopted by many industries to speed up and lower the cost of developing new products, show complex and innovative parts that make them more efficient and competitive in the market. Moreover it has the potential to improve supply chain performance due to its flexibility in manufacturing, economical use of materials, reduced environmental effect, and optimized product design.

Most studies demonstrate the advantages of AM technology. They mention the reasons for adopting AM from different perspectives and stress that its benefits outweighs its drawbacks. But before adopting AM technology, the benefits have to be weighed against the shortcomings and accordingly careful analysis and strategic decision are required.

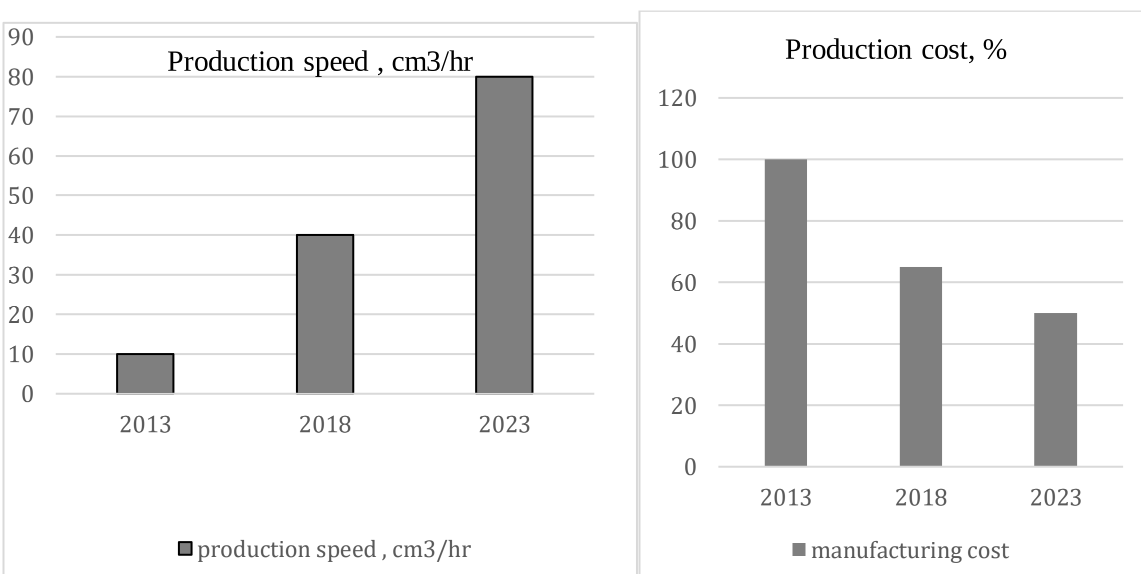

Figure 6 AM production cost and speed (Attaran, 2017)

2.8 Challenges of AM Technology

Most studies demonstrate the importance and applications of AM technology. They mention the reasons for adopting AM from different perspectives and adopting AM technology depends on many factors. Some articles also identify the barriers and challenges facing companies to adopt the technology. They stress the need for proper analysis before planning and applying the technology (Chatterjee et al., 2023; Prashar et al., 2023).

Although AM technology is a new technology that is poised to transform manufacturing and many other industries, it has its drawbacks (Attaran, 2017). Higher equipment and material costs, as well as standards and quality concerns, seem to be the main obstacles to wider implementation (Chatterjee et al., 2023; Prashar et al., 2023).

According to Attaran (2017) only objects that are smaller than the printer's casing can be produced using a 3D printer and the biggest objects that can be made are limited as a result. There are larger printers available, but they need a room big enough to accommodate them. Parts of a product are occasionally manufactured in segments due to a lack of a large enough printer; and this lengthens the assembly process and reduces some of its advantages.

Ronchini et al. (2023) have found in their study long production time, size and volume limitations, high initial investment, operational costs and lack of skills and knowledge to be the challenges of AM adoption facing the aerospace and automotive sectors.

The major obstacles of implementing AM technology are summarized below (Sonar et al., 2020)

- High equipment cost
- Post-processing is tiresome
- High initial effort required for calibration
- It needs highly skilled operator
- Availability of software is limited

Even though the cost of 3-D printing equipment is one current barrier to entry, it will not last very long as a reality. The cost of 3-D printers will go down as more manufacturers enter the market and as technological advancements continue (Attaran, 2017; Prashar et al., 2023).

Sonar et al. (2020) emphasized that choosing the right AM technology for particular industrial applications is a crucial step in the implementation of additive manufacturing. Additionally, a significant obstacle to AM adoption in many industries is the need to upgrade current capabilities or construct new infrastructure.

Since additive manufacturing (AM) is a relatively new technology compared to traditional methods, there is still a gap that needs to be filled in terms of AM development, standardization, and material certification (Prashar et al., 2023).

If 3D- printing is not properly regulated, its expansion and adaptation could have enormous social and commercial ramifications and this issue of 3-D printing regulation has already been raised in many countries (Chatterjee et al., 2023). Regulations and laws frequently do not advance with new technology at the same rate (Prashar et al., 2023). Basically, if a CAD design and a printer large enough to print the item are available, a product can be created quickly and without limitations raising the issue of regulations (Attaran, 2017).

2.9 AM Technology Adoption in Ethiopia

The study by Cirera et al. (2023) shows that the prevalence and adoption of AM technology among Ethiopian firms is rare as it is shown in Table 1. The table shows the adoption of the technologies under Industry 4.0, which includes AM technology. Out of these, the most widely used technology is cloud computing, which was reported as being used by 4.3 percent of all firms.

Table 1 Industry 4.0 Technologies adoption in Ethiopia (Cirera et al., 2023)

Technology	Mean	S.D.	Small	Medium	Large	Agri.	Manuf.	Service
Cloud Computing	4.3%	20.2	1.9%	10.1%	32.7%	1.4%	9.3%	4.0%
Big Data Analytics/AI	0.0%	0.0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Robots	0.0%	1.7	0.0%	0.0%	0.3%	n.a.	0.0%	n.a.
AM technology	**0.0%**	**1.5**	**0.0%**	**0.0%**	**0.2%**	**n.a.**	**0.0%**	**n.a.**
Other Advanced Manufacturing	1.2%	10.8	0.0%	0.3%	11.5%	n.a.	1.2%	n.a.
Precision Agriculture (IoT)	0.0%	0.0	0.0%	0.0%	0.0%	0.0%	n.a.	n.a.

Table 1 demonstrates that Ethiopia is still lagging far behind in embracing innovations and adopting new technology. There are many reasons for such condition. The major ones are knowledge gap about the existence and importance of these new technologies and shortages of skilled manpower who can operate or apply these technologies in the respective sector. There may be resistance or lack of motivation to shift from the established and status quo technology to the new ones. Due these facts, we can say that adoption and usage of AM technology in Ethiopia is almost rare.

2.10 Literature Gap

1. Based on the conducted literature review, some research gaps are identified as the following. Almost all the surveyed articles focused their study on developed countries regarding AM technology adoption and application. Woldesilassiea et al. (2024) retrieved 978 journals on AM technology from 2004 to 2023 and out of these publications, 70 journals were reviewed and the results of their review indicated that there is limited published research on AM technology in developing countries and most papers focused mainly their studies on AM technology adoption on non-metal manufacturing industries, service, automotive and airspace sectors. Figure 7 shows their findings about the number of AM technology journals produced with respect to the study by types of industry.
2. The majority of research on the adoption of AM technology focus on the companies that have adopted and using the technology; non-adopting companies are not included in these studies.

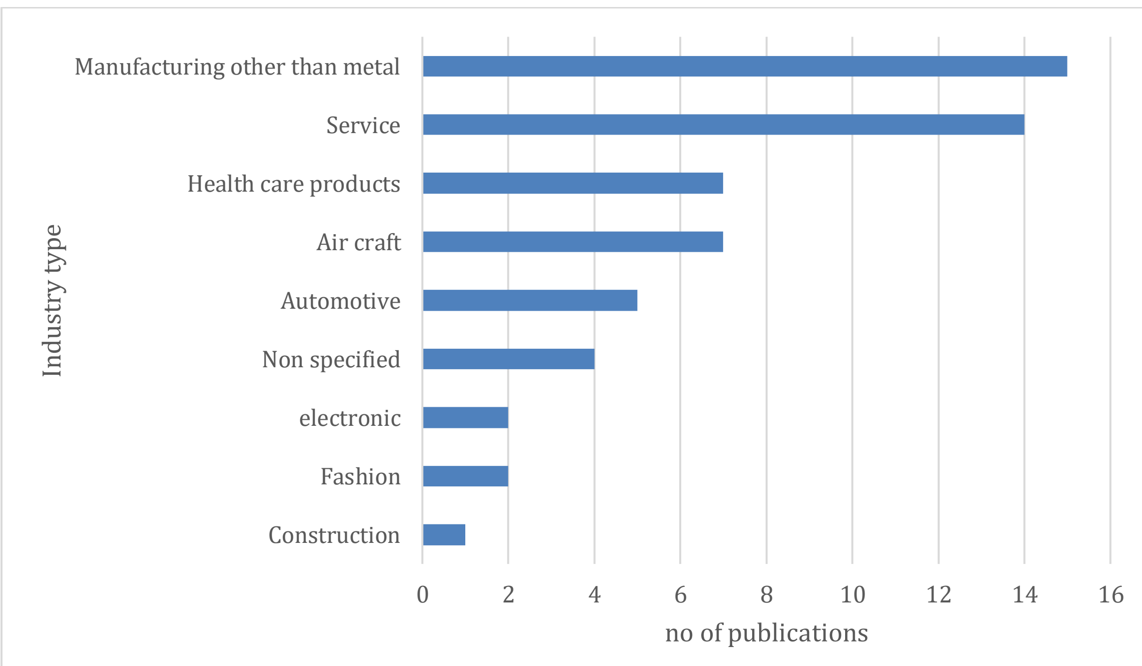

Figure 7 Publications per type of AM industry (Woldesilassiea et al., 2024)

3. Even most studies show the benefits of AM technology, to my best knowledge there is limited research regarding the adoption of AM technology for metal manufacturing process.
4. Within the context of our country, studies are rare about the AM technology adoption and its impact in metal manufacturing industries. Some authors such as Lemma et al. (2023) have made study on AM technology within Ethiopian footwear industry.

2.11 Model Development

In line with research question, this thesis examines how technologies are adopted in industrial manufacturing organizations using theories of innovation adoption. The literature suggests that studying technology adoption and usage can benefit from a foundational understanding of the Technology-Organization-Environment (TOE) framework. The TOE framework developed by Davis (1989) aligns with Rogers' diffusion of innovation theory (DIT), since both emphasize organizational internal and external factors, along with technological characteristics, when examining the factors that influence the adoption of new technologies. Similarly, the Technology Acceptance Model (TAM) is supported by the TOE framework. Like TAM, TOE makes the assumption that user behavior as an internal organizational trait is one of the elements affecting people's adoption and use of technology (Davis, 1989).When analyzing topics like technological adoption, implementation, and usage, the TOE framework has been a well-liked fundamental paradigm. Numerous studies on the adoption of information technology, including those on big data analytics, open systems, cloud computing, enterprise resource planning, electronic fund transfers, and cloud computing, have made use of the TOE framework (Maroufkhani et al, 2020). The current study has adopted the TOE framework and related theoretical links in the process of creating the AM technology adoption model since the TOE framework encompasses most of adoption models developed before it. The technical features of AM technology are referred to as the technological context in this study that are the perceived value, perceived compatibility, and perceived cost. The organizational context includes two organizational determinants such as top management support and organizational readiness while environmental context includes external pressure and perceived outside support. Figure 8 presents the proposed model of AM technology adoption for metal manufacturing industries. This framework guides the hypothesized relationships and the empirical analysis of this research.

Table 2 Summary of literature review for the model development

S/N	Theory or model	Construct	Selected references
1	Innovation diffusion theory	• Relative importance • Compatibility • Trailibility • Obserability • Complexity	Rogers (2003): Ramdani & Kawalek (2009) ; Oliveira & Martins (2011); Handfield et al. (2022)
2	Technology Acceptance Model (final version)	• Perceived usefulness • Perceived Ease of Use	Davis (1989); Davis & Venkatesh (1996); Dube et al. (2020) ; Tornatzky & Klein (1982); Sharma & Mishra (2014); Oettmeier & Hofmann (2017);Darbanhosseiniamirkhiz & Wan Ismail (2012)
3	TOE framework	• Top management support • Absorption capacity Perceived external support • External pressure	Tornatzky & Fleischer (1990); Awa et al. (2017); Dube et al. (2020); Angeles (2014); Musawa & Wahab (2012); Darbanhosseiniamirkhiz & Wan Ismail (2012); Maroufkhani et al., 2020; Chatzoglou et al. (2019); Ghobakhloo & Ching , 2019; Kulkarni et al. (2021) ; Bag, et al. (2023)

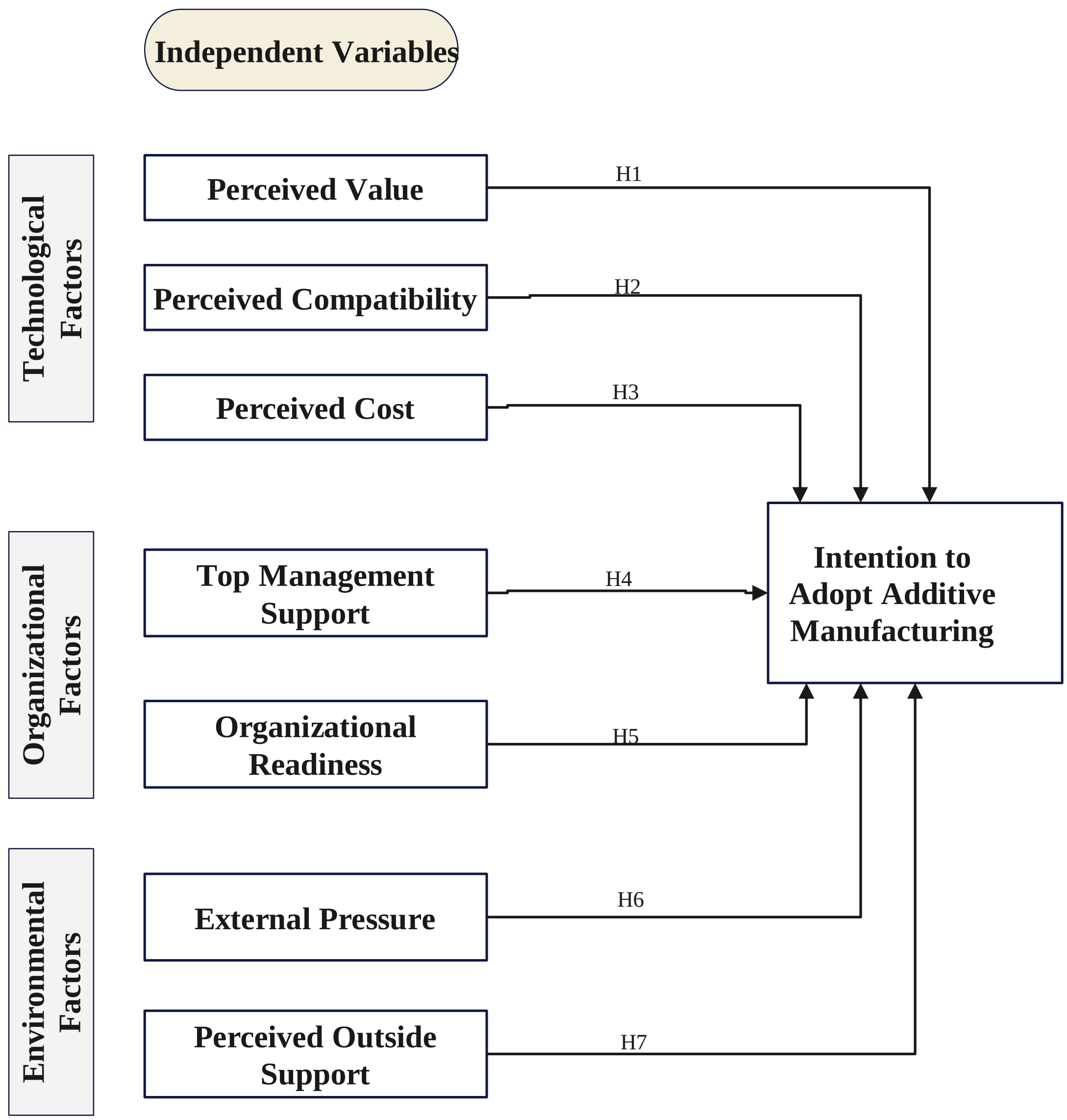

Figure 8 Conceptual model of the research (adapted from Maroufkhani et al., 2020 & Ghobakhloo & Ching , 2019)

2.12 <u>Hypothesis Development</u>
<u>Technological Aspects</u>

The first hypothesis links the perceived value of the new technology with the intention to adopt it. One of the technological components is the relative advantage, wherein the perceived value of the new technology to a certain organizational performance may have a significant impact on the organization's desire to adopt (Maroufkhani et al., 2020). Relative advantage is the degree to which technology adoption is viewed as superior to alternative forms of technology or the current technology employed in businesses and the benefits it provides to the organization (Rogers, 2003;

Ghobakhloo & Ching, 2019). Perceived value denotes the degree to which technological innovation is perceived as complying with the requirements, economic values and the culture of the technology adopters. At the implementation stage, a technological innovation is perceived as beneficial, if it delivers more advantages and values to the organization. Manufacturing SMEs will consider the future implementation of AM if they perceive it as potentially valuable. Therefore companies are ready to embrace a technology when they believe its values exceed those of the current technology. Hence based on the above argument, the following hypothesis is proposed

H1: *There is positive relationship between perceived value and the intention to adopt AM technology*

The degree to which a new technology is compatible with the company's current system is examined by perceived compatibility (Awa et al., 2017). The degree to which technology adoption is deemed compatible with an organization's needs, culture, and business practices is determined by several factors (Chen et al., 2015; Ghobakhloo & Ching, 2019). If businesses realize that AM technology is compatible with their organizational structure, procedures, and practices, they will be more likely to implement it internally. Hence based on the above argument, the following hypothesis is proposed

H2: *There is positive relationship between perceived compatibility and the intention to adopt AM technology*

Perceived cost is defined as the perceived financial cost as a result of considering procuring or procuring new technology equipment. This might include both operating and implementation costs. If the technology is complicated, it is evident firms must invest much more in order to pay for the upfront costs of hardware, software, and license (intellectual rights issue) as well as indirect implementation costs (Ghobakhloo & Ching , 2019). Thus financial resource limitations force management to be cautious about their capital spending and investments on new technology. Only company with sufficient financial resources would consider the adoption of AM technology to be a reasonable project to pursue. Therefore, company owner or managers are less likely to embrace new technologies if they perceive that the technology is more costly. Hence based on the above argument, the following hypothesis is proposed

H3: *There is negative relationship between the perceived cost and the intention to adopt AM technology*

<u>Organizational Aspects</u>

The organizational point of view highlights the characteristics and particular resources of an organization that are crucial for technological adoption. The degree to which the management body comprehends and accepts the potential of new technology is referred to as top management support. Since the inclination for adoption relates to the level of top managers' or leaders' innovativeness, decisions and support to adopt new technology rely heavily on almost members of the top management team. Their support is crucial for the adoption of an innovation and they serve as the link between individual and organizational technology adoption measures (Bag et al., 2023). Top management support begins with the interest in the new technology, initiation and promotion for its adoption and support rendered during adoption. Previous research has indicated that effective innovation adoption is significantly influenced by top management support (Chen et al., 2015). Thus, based on the above argument, the following hypothesis is suggested

H4: *There is positive relationship between top management support and the intention to adopt AM technology*

Organizational readiness refers to a company's capability and willingness to implement new technology (Gangwar, 2018). It represents the firm’s capability to manage and invest in the adoption of new technology including technical capability and expertise. Technological infrastructure, knowledge, financial, human, and managerial commitment to change are all components of organizational readiness (Maali et al., 2020). Businesses must create the necessary hardware, software, and infrastructure and a skilled workforce for adopting new technologies and if it is constrained in these resources, it is unlikely to introduce the technology (Maroufkhani et al., 2020; Bag et al., 2023). Thus, based on the above argument, the following hypothesis is suggested

H5: *There is positive relationship between organizational readiness and the intention to adopt AM technology*

<u>Environmental Aspects</u>

Environmental factors are those elements that organizations may confront with their external boundaries and they are usually more delicate to the dynamic external ecosystem (Maroufkhani et al., 2020) and Bag et al., 2023). According to Ghobakhloo & Ching (2019), competitive pressures are external environmental factors that prompt an organization to adopt new technology and it is the pressure that comes to a company from its competitors, suppliers, customers and other relevant stakeholders. The greater the pressure on companies to compete, the greater the expectation that new technology will be successfully adopted. Some researchers believe that competitors' growing use of AM adoption could encourage business owners and managers to successfully implement the technology. Thus, based on the above argument, the following hypothesis is suggested.

H6: *There is positive relationship between external pressures and the intention to adopt AM technology.*

A key component of adoption is perceived external support, which is defined as the ongoing help from a vendor or other third party to encourage businesses to innovate and successfully integrate new technology. Businesses can strengthen their capacity for innovation by learning from vendors (Maroufkhani et al., 2020 ; Bag et al., 2023). Companies prefer to adopt new technology if they perceive that the potential risks of new technology can be minimized through getting the necessary support from the suppliers. Local agencies and suppliers can offer basic and advanced training for companies to implement new technologies. Vendors who work with emerging technologies gain the expertise needed to help companies troubleshoot issues that can interfere with their daily activities (Bag et al., 2023). One of the most important factors influencing the success of innovations and the adoption of those innovations is external support. Thus, based on the above argument, the following hypothesis is suggested.

H7: *There is positive relationship between perceived outside support and the intention to adopt AM technology.*

CHAPTER 3

3. Research Methodology

Introduction

This study's research methodology describes the study's approach, design, data sources, sampling techniques, sample size, tools and methods for collecting data, and data analysis strategies. This research is an empirical type research with quantitative and qualitative methods.

The research methodology is focused on the following research questions

1. What are the determinants that influence the intention to adopt AM technology?
2. How do AM technology benefits impact business performance in manufacturing system?
3. What are the challenges in adopting AM technology?

3.1 Research Design

The research process is guided by the research design framework in order to meet its objectives as shown in fig 9. The process spans from problem identification, literature review on AM technology, relevant adoption theories and hypotheses development , proceeds through data collection instrument development, data collection, analysis and synthesis , interpretation, culminating finally in the formulation of conclusion and recommendations.

Literature Review

To obtain a comprehensive understanding of the subject matter, find the literature gap and formulate research questions, a detailed review of relevant theories was done. After literature review, a model and hypotheses are developed which guide the empirical analysis. The literature review used various sources including online open resources with many scholarly peer reviewed and published article journals, books and company and government reports.

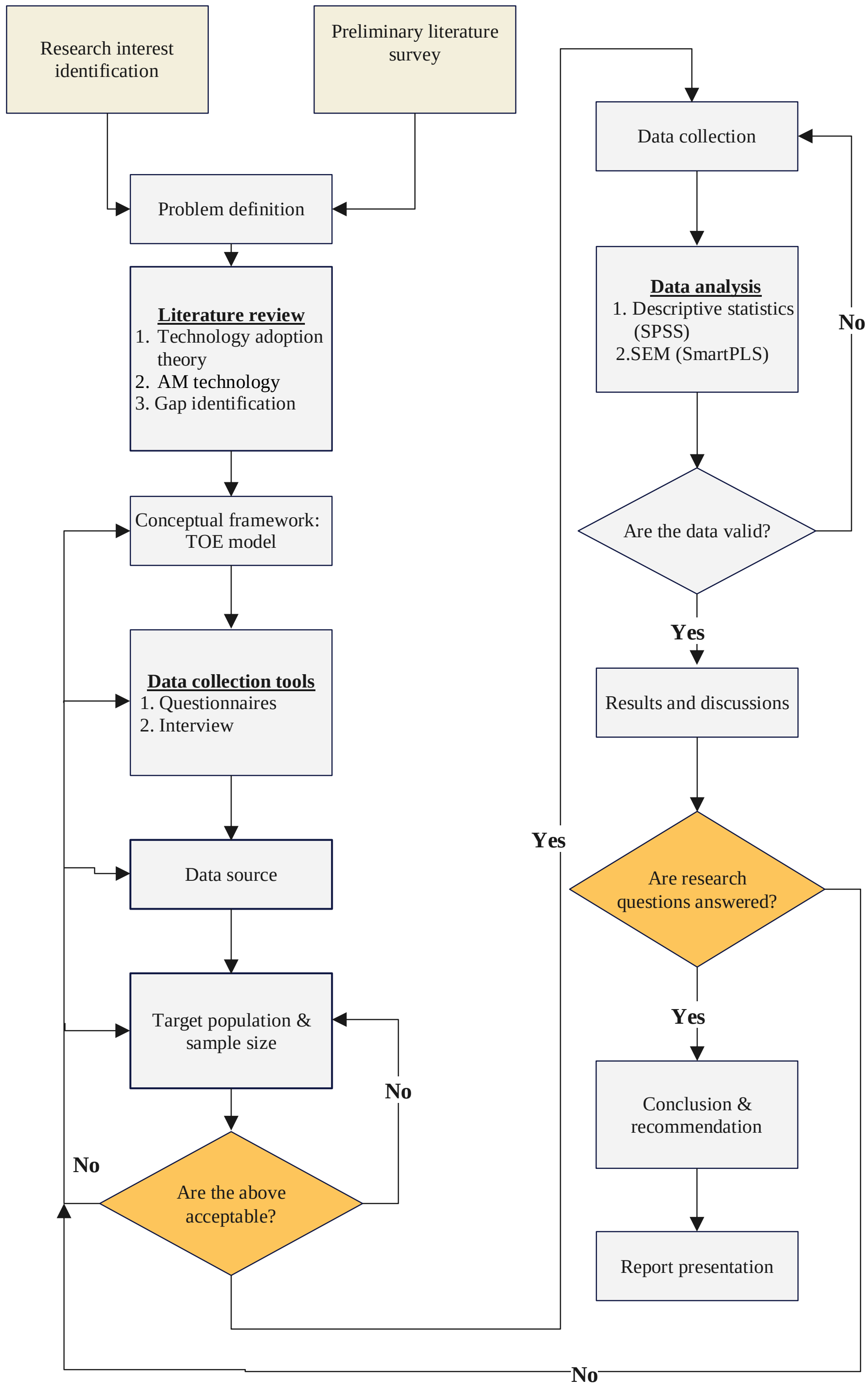

Figure 9 Research methodology design

Research Approach

This study employs a mixed research methodology that incorporates both qualitative and quantitative research methods. According to Creswell (2014), the "mixing" or blending of the two types of approaches results in a stronger understanding of the problem or question than either type alone. This research method has also regained popularity, with many studies praising its benefits for better understanding and/or validating results.

3.2 Data Collection

To answer the research questions, both primary and secondary sources of data are used

A) Primary Data

Primary data are obtained by taking data through physical observation, questionnaires and interview that are made with senior members and experts with knowledge and experience on conventional and additive manufacturing technologies working in Manufacturing Technology and Engineering Industry Research and Development Center (MTEIRDC) in Ethiopia formerly known as Manufacturing Industry Development Institute (MIDI) supporting the industry, various metal manufacturing industries and Ministry of Innovation & Technology

I. Questionnaire development

Questionnaires for quantitative data collections are developed based on the developed model and hypotheses which are adapted from TOE adoption theory that answer the research questions. Similar questionnaire was used in various studies by scholars Chatzoglou et al. (2019); Kulkarni et al. (2021) and Bag, et al. (2023) who proved the validity of the questionnaires. Some of the measurement items of the questionnaire are modified in order to be keeping up with the study's context.

The questionnaire is rated with seven point Likert scale to measure the degree of influence of the measuring indicators and variables that determines the intention to adopt AM technology in Ethiopian metal manufacturing industries. The seven point Likert rating scale is ranked as follows:

1= Strongly Disagree, 2 = Disagree, 3 = Somewhat Disagree, 4 = Neutral, 5= Somewhat Agree, 6= Agree, 7= Strongly Agree

The reason for choosing seven point Likert rating scale is it is commonly employed in surveys and questionnaires by many scholars and studies show that a seven Likert scale is effective in terms of reliability and validity coefficients (Tanujaya et al., 2022). A seven Likert scale is used in similar technology adoption studies by some scholars Chatzoglou et al. (2019), Kulkarni et al. (2021) and Bag et al. (2023).

There are 30 measuring items of adoption factors in this questionnaire (Table 3). These questionnaires are forwarded to professionals, engineers, technologists and experts from Manufacturing Technology and Engineering Industry Research and Development Center (MTEIRDC), various metal manufacturing industries in Ethiopia and Ministry of Innovation and Technology.

Table 3 Measurement Items of the Study

Independent variable	No of indicators	Source
Technological factors		
Perceived value	5	Chatzoglou et al. (2019); Kulkarni et al. (2021); Bag et al. (2023)
Perceived compatibility	3	Bag et al. (2023); Maroufkhani et al. (2020) Ghobakhloo et al. (2019)
Perceived cost	4	Ghobakhloo et al. (2019)
Organizational factors		
Top management support	4	Bag et al. (2023); Maroufkhani et al. (2020)
Organizational readiness	4	Bag et al. (2023); Maroufkhani et al. (2020)
Environmental factors		
External pressure	4	Bag et al. (2023); Maroufkhani et al. (2020)
Perceived outside support	3	Bag et al. (2023); Maroufkhani et al. (2020)
Dependent variable		
AM adoption intention	3	Chatzoglou et al. (2019)

II. Interviews –In addition interview was conducted by holding discussions with three participants from senior members of MTEIRDC. The interview was mainly focused on the impact of AM technology on business performance and the challenges of adopting the technology. Also points were raised on technology adoption strategy, policy, general reflection on AM technology and problems faced by current metal manufacturing industries

III. <u>Observation:</u> Physical observation was made at Sabean Base Metal Engineering PLC which manufactures hand tools, articles and other products as a sample to see the current metal fabrication process and the products.

B) <u>Secondary data</u>

Secondary data are collected from literature review regarding technology adoption process, technology adoption theories and models, applications, benefits and challenges of AM technology. Moreover MTEIRDC company's report and relevant government data about the metal industry are collected to support the research objectives

3.3 Sampling Technique

According to Cohen et al. (2007), the problem of defining the population that the research will concentrate on gives rise to the sampling techniques. Moreover, costs, time, and accessibility often make it not feasible for researchers to get information from every member of the population. Researchers frequently need to gather data from a smaller group or subset of the total population in order to guarantee that the knowledge gained is representative of the entire population under study.

<u>Purposive Sampling</u>

Non-probability with purposive and quota sampling of the population is used in this study. The quota for each population group that makes up the target population is determined to arrive at the sample size. The quota is established by the availability of the relevant participants necessary for data collection in each group.

Saunders et al. (2016) states that purposive sampling allows the researcher to choose by using his judgment directly participants that have the necessary information and data that are pertinent and helpful for the research instrument, answering the research question and meeting the overall objective of the study. Here, the researcher has limited the sampling to particular categories of individuals who meet certain criteria or are the only ones with the necessary information. It entails choosing participants who are most positioned to give the necessary information or who are in an advantageous situation. Consequently, when persons meet the criteria or possess the desired information, purposive sampling is employed (Sekaran, 2003).

Purposive sampling cannot be regarded as statistically representative of the target population. The purpose of the research question(s) and objectives will determine the reasoning behind the researcher's strategy for choosing cases for a purposive sample (Saunders et al., 2016).

3.4 Target Population and Sample Size

The MTEIRDC, metal manufacturing industries, and Ministry of Innovation and Technology, are served as a sampling frame for this study, giving the researcher access to the target population. This target population group consists of experts, metal technology researchers, senior members and professionals with knowhow and experience on conventional and additive manufacturing technologies, working in metal manufacturing industries, research and development (R&D) center and technology and innovation departments. As a result, the researcher has looked and assessed with respective organization to determine the participants' sample size of each organization which is shown in Table 4. In total the sample size is one hundred seventy (170) respondents and in fact this sample size is sufficient to bring the data collection process to a saturation point.

Table 4 Target population and sample size

S/N	Company /institute	Sample size	Professionals	Data instrument
1	Manufacturing Technology and Engineering Industry Research and Development Center (MTEIRDC)	40	Engineers ,metal technologists, manufacturing and quality control technicians and management members, researchers(RD)	Interview/ questionnaire
2	Metal manufacturing industries	100	Engineers ,metal technologists, manufacturing and quality control technicians	Questionnaire
3	Ministry of Innovation and Technology	30	Engineers, technologist, senior members	Questionnaire
	Total sample size	170		

3.5 Data Analysis Method

Before analysis, questionnaires with incomplete and invalid responses are excluded. Then the data are sorted and coded. The data are analyzed into two phases using SPSS (Statistical Package for Social Scientists) version 23 and SmartPLS-SEM version 4.

The SPSS is used to analyze descriptive statistics, including population demographic data such as mean, standard deviation, percentage, and frequency distributions, as well as mean ratings on a seven-point Likert scale rating.

The SmartPLS is used to analyze correlation, multicollinearity, factor loading, reliability, validity and structural equation modelling (SEM) with the determination of path coefficients, significance (p-values) and t-scores. The final goal of the SEM modelling is to test the proposed hypotheses either for acceptance or not acceptance.

Reasons for using PLS-SEM is if the data exhibits non-normal distributions and the sample size is limited (Magno, et al., 2024). Actually, partial least square analysis is widely employed in today's research setting to support the derivation of managerial recommendations that are predictive in nature, as well as to test proposed models. In addition, partial least square analysis is best suited for causal-predictive relationship analysis and makes it a useful method to balance explanation and prediction (Becker et al., 2022a; Hair et al., 2022).

Descriptive Statistics

The computed composite mean scores of the respondents’ seven point Likert scale rating using descriptive statistics analysis give meanings about the participants' responses regarding the level of agreement of each measuring indicators of both independent and dependent variables of the questionnaire. This gives highlights about the responses before structural equation modelling (SEM) is done.

Structural Equation Modelling (SEM)

Correlation Analysis

A statistical method for determining the direction and strength of a relationship between two variables is correlation analysis. A correlation coefficient between -1 and +1 may be the correlation matrix's output. In this framework, a perfect positive relationship is denoted by a correlation coefficient of +1, a perfect negative relationship by a correlation coefficient of -1, and no linear relationship at all is indicated by a coefficient of 0. According to Saunders et al. (2016) and Hair et al. (2014) the following table serves as the basis for the classification of relationship strength. Hence the correlation is calculated to determine the coefficient of correlation among independent variables (perceived value, perceived compatibility, perceived cost, top management support, organizational readiness, external pressure, perceived outside support) and the dependent variable (AM adoption intention)

Table 5 Classification of the Strength of Correlation

Positive value	**Negative value**	**Correlation**
0.8 to 1	- 0.8 to -1	Very Strong
0.6 to 0.8	-0.6 to - 0.8	Strong
0. 35 to 0.6	-0.35 to - 0.6	Moderate
0.2 to 0. 35	-0.2 to - 0.35	Weak
0 to 0.2	0 to-0.2	Very Weak

Source**:** Saunders et al. (2016) and Hair et al. (2014)

Reliability Test

A measure's reliability guarantees consistent measurement over time and amongst the different components of the instrument. Stated differently, a measure's reliability is a reflection of the consistency and stability with which the instrument measures the construct and aids in determining the measure's quality (Sekaran, 2003).

Composite reliability (CR) and Cronbach's Alpha tests are used to assess consistency and reliability among the questionnaire's indicators. As suggested by Hair et al. (2019), the values of factor loadings, Cronbach's Alpha and composite reliability (CR) should be ≥ 0.7.

Validity Test

According to Hair et al. (2022), validity is the degree to which a measure faithfully represents the intended outcome. To ensure validity, the item to be measured must be well understood and made as accurate and correct as feasible. Validity tests are done using average variance extraction (AVE) and discriminant validity criteria which states that the inter-variable correlation coefficient should be less than the square root of the corresponding AVE.

Multicollinearity

There should not be perfectly linear relationships between the independent variables, according to this assumption. When there is strong correlation between multiple independent variables, this is known as multicollinearity. The presence of multicollinearity among the independent variables is examined using the Variance Inflation Factor (VIF). A variable with a VIF value greater than 5 indicates the possibility of a multicollinearity problem.

Path Coefficients (ß), T-Scores and P-Values Analysis

In order to test the relationship between the independent variables and dependent variable for statistically significance relationship and hence test the proposed hypothesis, a structural equation modelling (SEM) is employed using the smartPLS4-SEM to find the values of path coefficients β, t statistic and p-values. Table 6 shows the summary of parameters with their threshold values

Table 6 Structural Equation Model Analysis Criteria

SEM Item	**Threshold Value**
Cronbach's Alpha	>0.7
Composite Reliability(CR)	>0.7
Average Variance Extracted (AVE)	>0.5
Validity (inter-construct correlation coefficient)	< √AVE
Variance Inflation Factor (VIF)	< 5
Path Coefficients (β)	> 0.1
T-Score	>1.96
Statistically Significance (P-Value)	< 0.05

CHAPTER 4

4. Data Analysis, Presentation and Interpretation

Introduction

The results of the data analysis and interpretation of the survey, interview, and physical observation data are presented in this chapter. To create the complete data required for the analysis, the collected data are first rearranged and coded. Using SPSS version 23 software and SmartPLS version 4, statistical procedures are used to analyze the data collected from the questionnaires in accordance with the overall goal of the research. In the first section, the respondents' demographic profile is covered. Descriptive statistics like mean, standard deviation (SD), and frequency distribution percentage are calculated using the SPSS to depict the respondents' degree of agreement when rating each measuring items of adoption factors for AM technology using the seven point Likert rating scale in seven levels. Following this section, SmartPLS is used to analyze correlation, multi-collinearity, factor loading, reliability, validity and structural equation modelling (SEM).

Response Rate

A total of 170 questionnaires is distributed in person to the respondents and follow up calls were made. Out of the collected questionnaires, one hundred seven (107) are filled properly and the rest are found to be incomplete. Consequently, the total response rate is 63%, and the collected data is analyzed and discussed in relation to the study.

S/N	Company /institute	Distributed questionnaires	Filled questionnaires
1	MTEIRDC	40	29
2	Metal manufacturing industries	100	68
3	Ministry of Innovation and Technology	30	10
	Total	**170**	**107**

4.1 Descriptive Statistics

Demographics of the Respondents

The study's respondents' demographic information includes their gender, age, profession, educational attainment, and years of work experience which are shown in Table 8

Table 7 Demographic information of respondents

Characteristics	Frequency	Percentage
Gender		
Male	92	86 %
Female	15	14 %
Age		
25-34	67	63 %
35-44	28	26 %
45-54	12	11 %
55-60	-	-
Educational level		
B.Sc degree	77	72%
M.Sc degree	20	18 %
Advanced diploma	10	10 %
Job title		
Team leader	5	4 %
Metal Researcher	12	11 %
Engineer	35	33 %
Metal technologist	20	19 %
IT professionals	6	6 %
Quality controller	5	4 %
Technician	25	23 %
Production head	4	3 %
Years of experience		
Below 3 yrs	7	6 %
3 to 5 yrs	38	36 %
6 to 10 yrs	47	44%
11 to 15 yrs	9	9 %
Above 15 yrs	6	5 %

Table 8 shows that 86 % of the respondents are men and 14% are women. This suggests that men make up the majority of professionals. The age distribution reveals that the majority of employed individuals are young professionals, with 63% falling between the 25 and 34 age range, 26 %

between the 35 and 44 age range, and 11% between the 45 and 54 age range. 72% of individuals possess a first degree, 18% a second degree, and 10% an advanced diploma. The majority of them hold a first-degree degree. In terms of profession, 33% of workers are engineers, followed by technicians (23%), metal technologists (19%), metal researchers (11%), IT specialists (6%), team leaders (4%), bquality controllers (4%), and production heads (3%). Engineers make up the majority of them.

With respect to years of work experience, 5 % have more than 15 years, 9 % have 11 to 15 years, 44 % have 6 to 10 years, 36 % have 3-5 years, and 6 % have less than 3 years. This demonstrates that the majority of responders have worked for at least six years.

4.2 Assessment of Mean Score Values

Perceived Value (PV)

Table 8 Mean value and frequency distribution for Perceived value

Code	Question	No. of Respondents							Mean ±SD
		1	2	3	4	5	6	7	
PV1	AM reduces operational cost	4	13	28	19	15	22	6	4.10±1.60
PV2	AM can build lightweight & complex products	3	10	20	19	10	25	20	4.66±1.76
PV3	AM enables reduction & simplification of manufacturing steps	7	24	34	26	21	16	13	4.06±1.60
PV4	AM enables customized production	2	6	28	25	16	20	10	4.37±1.50
PV5	AM enables rapid prototyping process for new product development	4	4	16	25	17	25	16	4.74±1.58

1= Strongly Disagree, 2 = Disagree, 3 = Somewhat Disagree, 4 = Neutral, 5= Somewhat Agree, 6= Agree, 7= Strongly Agree

From Table 9, the mean scores are all above mid-point (4.00) and this indicates that the respondents somewhat agree that the factor perceived value is important in influencing their intention to adopt AM technology. Out of these indicators, PV2 and PV5 have mean score of 4.66 and 4.74

respectively which have higher values out of these mean scores. This shows respondents understand that AM technology can gain competitive advantage for the firm by building lightweight & complex products and enabling rapid prototyping production for new product development

Perceived Compatibility (PC)

Table 9 Mean value and frequency distribution for Perceived Compatibility

Code	Question	No. of Respondents							Mean ± SD
		1	2	3	4	5	6	7	
PC1	AM is compatible with existing manufacturing system	4	21	18	17	23	16	8	4.07±1.67
PC2	AM is consistent with the organization's business practices and needs	1	8	13	28	17	29	11	4.71±1.47
PC3	AM fits with the organization's behavior and culture	4	5	17	18	12	29	22	4.90±1.71

From Table 10 the mean scores are all above mid-point (4.00) and this indicates that the respondents somewhat agree that the factor perceived compatibility is important in influencing their intention to adopt AM technology. Out of these indicators, PC2 and PC3 have mean score of 4.71 and 4.90 respectively. This shows respondents agree that in order to adopt AM technology it needs to be compatible with their organization's business practices, needs, behavior and culture

Perceived Cost (COST)

Table 10 Mean value and frequency distribution for Perceived Cost

Code	Question	No. of Respondents							Mean ± SD
		1	2	3	4	5	6	7	
COST1	AM technology incurs high implementation cost	5	10	15	11	16	29	21	4.81 ± 1.81
COST2	Learning to use AM technology incurs more cost for companies	2	5	23	38	13	24	2	4.26 ± 1.62
COST3	AM technology incurs high cost to maintain	2	6	32	38	11	15	3	4.00± 1.27
COST4	AM technology after sales service incurs high cost	4	11	17	34	19	17	5	4.15± 1.46

From Table 11 the mean scores for the indicators of the variable cost are all above mid- point (4.00) and this indicates that the respondents somewhat agree that the cost of AM technology is important in influencing their intention to adopt AM technology. Out of these indicators, COST1 have higher mean score of 4.81 which shows the respondents think that AM technology will incur high implementation cost. The other indicators also imply learning and maintaining AM technology will incur cost.

Top Management Support (TMS)

Table 11 Mean value and frequency distribution for Top Management Support

Code	Question	No. of Respondents							Mean ± SD
		1	2	3	4	5	6	7	
TMS1	Top management creates support for AM adoption	4	11	16	23	18	27	8	4.43 ± 1.60
TMS2	Top management initiates the use of AM technology in the organization	2	7	20	18	14	30	16	4.77 ± 1.62
TMS3	Top management promotes the use of AM technology within the organization	5	6	18	31	17	25	5	4.36± 1.49
TMS 4	Top management is interested in adopting AM technology	4	7	15	32	13	27	9	4.50± 1.55

From Table 12 the mean scores for the indicators of the variable top management support are all above mid-point (4.00) and this indicates that the respondents somewhat agree that the top management support is important in deciding the adoption of AM technology. Out of these indicators, TMS2 have higher mean score of 4.77 which indicates that the respondents think initiation for AM technology adoption should come first from top management body. In other words they give more importance for the initiation of AM adoption to be given by top management body than other types of support.

<u>Organizational Readiness (OR)</u>

Table 12 Mean value and frequency distribution for Organizational Readiness

Code	Question	No. of Respondents							Mean ± SD
		1	2	3	4	5	6	7	
OR1	Company's structure, system and culture prevents us from adopting AM technology	1	1	13	18	24	29	21	5.18 ±1.38
OR2	Lacking capital/financial resources prevents us from adopting AM technology	-	3	11	20	32	20	21	5.10±1.35
OR3	Lacking skilled manpower prevents the business from adopting AM technology	-	2	14	22	23	24	22	5.11±1.35
OR4	Lacking proper infrastructure prevents us from adopting AM technology	1	6	14	28	24	18	16	4.70± 1.46

From Table 13 the mean scores for the three of indicators OR1, OR2 and OR3 of the variable organizational readiness have a value more than 5.00. The respondents strongly agree that appropriate and sufficient resources, infrastructure, flexible working system, organizational structure and culture are vital to introduce new technology into the company. So they believe that if the company is ready in these aspects, AM technology can be adopted. This construct has got higher mean score than others meaning organizational readiness is given more importance for technology adoption.

External Pressure (EP)

Table 13 Mean value and frequency distribution for External Pressure

Code	Question	No. of Respondents							Mean ± SD
		1	2	3	4	5	6	7	
EP1	Our choice for adoption of AM technology would be influenced by our competitors that use the technology	2	9	20	37	29	10	2	5.03± 1.22
EP2	Our company would adopt AM technology in response to what competitors are doing	2	4	20	29	24	16	12	4.54± 1.43
EP3	Our company is under pressure from competitors to adopt AM technology	4	10	23	23	17	21	9	4.30±1.60
EP4	Our company is under pressure due to volatile customer needs for various and new products	2	9	15	19	13	36	13	4.80±1.61

From Table 14 the mean scores for the three of indicators EP1, EP2 and EP4 of the variable external pressure have a value of 5.03, 4.54 and 4.80 respectively. The respondents strongly agree that pressure from externals such as competitors, relevant stakeholders and customer (market demand) are almost equally important in pressurizing their organization or management to adopt AM technology in order to stay competitive in the market. So they are aware that external environmental factors have substantial influence on the intention to adopt AM technology. This construct has got second mean score value after the variable organizational readiness.

Perceived Outside Support (POS)

Table 14 Mean value and frequency distribution for Perceived Outside Support

Code	Question	No. of Respondents							Mean ± SD
		1	2	3	4	5	6	7	
POS1	Local agencies/ suppliers can provide required training for AM adoption	4	10	16	40	18	13	6	4.13±1.42
POS2	Local agencies/suppliers can provide effective technical support for AM technology adoption	4	8	19	28	21	22	5	4.30±1.47
POS3	Local agencies/suppliers actively market AM technology adoption	5	12	20	23	23	16	8	4.19±1.59

From Table 15 the mean scores for the indicators of the variable perceived outside support are all above mid- point (4.00) and this indicates that the respondents somewhat agree that the perceived outside support is important in deciding the adoption of AM technology. Out of these indicators, POS2 have higher mean score of 4.31 which indicates that the respondents think if there is technical support after sales, they are likely to have intention to adopt AM.

4.3 Assessment of the Measurement Model

4.3.1 Correlation

Before the data is further analyzed, the coefficients of correlation between the independent variables were examined. Table 16 shows higher correlation coefficient to be 0.680 between the independent variables and the rest correlation coefficients are low which show weak correlations among them and the data is acceptable for further analysis.

Table 15 Correlation coefficients between variables

	AM	COST	EP	OR	PC	POS	PV	TMS
AM	1.000							
COST	0.601	1.000						
EP	0.706	0.652	1.000					
OR	0.578	0.490	0.503	1.000				
PC	0.154	0.076	0.256	0.013	1.000			
POS	0.738	0.564	0.557	0.460	0.203	1.000		
PV	0.681	0.680	0.583	0.441	0.093	0.530	1.000	
TMS	0.708	0.658	0.656	0.516	0.157	0.570	0.554	1.000

Note: **PV:** Perceived value; **PC**: Perceived Compatibility; **COST**: Perceived Cost; **TMS**: Top Management Support; **OR**: Organizational Readiness; **EP:** External Pressure; **POS**: Perceived Outside Support

4.3.2 Reliability and Validity

To measure the reliability and validity of the variables, the factor (outer model) loadings, the Cronbach's alpha , composite reliabilities (CR) and average variance extracted (AVE) of the variables were computed after producing using the SmartPLS structural equation modelling(SEM) that shows the relationship between the independent and dependent variables. The values of factor loading, the Cronbach's alpha, CR and AVE should be higher than 0.7, 0.7, 0.7, and 0.5 respectively (Hair el at, 2019).

All the factor loading values are more than the thresh hold value of 0.7 except one variable which is the indicator of the perceived compatibility (PC2) with the value of 0.697 almost near to the thresh hold value and can be accepted. So the values of the factor loadings show all measuring indicators fully measure the respective latent variables as shown in Table 17.

The values of the Cronbach's alpha and composite reliabilities (CR) for all variables are more than the threshold value of 0.7 which show the measurements are reliable and consistent. All the average variance extracted (AVE) values are more than threshold value of 0.5 which show the measurements are valid &demonstrate their convergent validity is acceptable as shown in Table 18.

Table 16 Factor Loading and VIF

Item	Factor Loading	VIF	Item	Factor Loading	VIF
AM1	0.913	2.628	**POS1**	0.907	2.438
AM2	0.894	2.457	**POS2**	0.885	2.267
AM3	0.895	2.432	**POS3**	0.817	1.667
COST1	0.786	1.736	**PV1**	0.869	2.507
COST2	0.878	2.362	**PV2**	0.769	1.772
COST3	0.863	2.615	**PV3**	0.827	2.172
COST4	0.852	2.480	**PV4**	0.816	2.016
EP1	0.770	1.639	**PV5**	0.724	1.529
EP2	0.851	2.028	**TMS1**	0.894	3.120
EP3	0.814	1.795	**TMS2**	0.830	1.962
EP4	0.808	1.750	**TMS3**	0.848	2.540
OR1	0.881	2.495	**TMS4**	0.865	2.259
OR2	0.861	2.527	**POS1**	0.907	2.438
OR3	0.879	2.633	**POS2**	0.885	2.267
OR4	0.883	2.738	**POS3**	0.817	1.667
PC1	0.879	1.520			
PC2	0.697	1.368			
PC3	0.788	1.347			

Note: **PV:** Perceived value; **PC**: Perceived Compatibility; **COST**: Perceived Cost; **TMS**: Top Management Support; **OR**: Organizational Readiness; **EP:** External Pressure; **POS**: Perceived Outside Support; **AM**: Intention to adopt AM

Table 18 Measurement Model

	Cronbach's alpha	Composite reliability (rho-a)	Composite reliability (rho-c)	Average variance extracted (AVE)
AM	0.884	0.887	0.928	0.812
COST	0.867	0.870	0.909	0.715
EP	0.826	0.829	0.885	0.658
OR	0.899	0.905	0.930	0.767
PC	0.711	0.774	0.833	0.627
POS	0.839	0.848	0.903	0.757
PV	0.861	0.866	0.900	0.644
TMS	0.882	0.884	0.919	0.739

In addition to the AVE (convergent validity), the discriminant validity was tested using both Heterotrait–Monotrait (HTMT) and Fornell–Larcker criterion as shown in Tables 19 and 20 respectively. The criteria states that a construct's square root of its average variance extracted (AVE) values must be higher than the correlation it has with any other construct. The results show that all divergent validity values satisfy the criteria for validity.

Table 19 Discriminant validity using HTMT

	AM	COST	EP	OR	PC	POS	PV	TMS
AM								
COST	0.685							
EP	0.822	0.770						
OR	0.644	0.546	0.580					
PC	0.179	0.148	0.338	0.090				
POS	0.853	0.658	0.668	0.533	0.269			
PV	0.778	0.780	0.685	0.498	0.134	0.617		
TMS	0.798	0.749	0.765	0.581	0.191	0.654	0.630	

Note: **PV**: Perceived value; **PC**: Perceived Compatibility; **COST**: Perceived Cost; **TMS**: Top Management Support; **OR**: Organizational Readiness; **EP**: External Pressure; **POS**:Perceived Outside Support: **AM**: Intention to adopt AM

Table 20 Discriminant validity using Fornell & Larcker

	AM	COST	EP	OR	PC	POS	PV	TMS
AM	0.901							
COST	0.601	0.846						
EP	0.706	0.652	0.811					
OR	0.578	0.490	0.503	0.876				
PC	0.154	0.076	0.256	0.013	0.792			
POS	0.738	0.564	0.557	0.460	0.203	0.870		
PV	0.681	0.680	0.583	0.441	0.093	0.530	0.803	
TMS	0.708	0.658	0.656	0.516	0.157	0.570	0.554	0.860

Note: **PV**: Perceived value; **PC**: Perceived Compatibility; **COST**: Perceived Cost; **TMS**: Top Management Support; **OR**: Organizational Readiness; **EP:** External Pressure; **POS**: Perceived Outside Support; **AM** : Intention to adopt AM

After examining the reliability and validity, the data were examined whether there exists for multi-collinearity among the variables. The variance inflection factor (VIF) is used to check the multi-collinearity and Table 17 shows VIF for each variable. From this table, all VIF values are less than 5 which proves there is no multicollnearity issue.

4.4 Assessment of Structural Model

The structural model is generated to show important parameters that show the degree of relationship between the independent and dependent variable and whether the model is satisfactorily fit. To generate this model non parametric bootstrapping with 5000 replications was used. First from the generated model, the R squared and the adjusted R2 values are found to be 0.763 and 0.746 respectively. This demonstrated that the adoption dimensions together account for

76.3% of the variation in AM adoption, with other variables not accounted in this study influencing the remaining 23.7% of the variation. As a result, it can be concluded from the R-squared value that the independent variables have a greater power to explain the dependent variable and this shows the model fits satisfactorily.

Next the results of the bootstrapping shows the path coefficients and the associated p-values of the direction and strength of the relationship between the independent and dependent variables. From Table 21, the independent variable perceived value (PV) has a value of $\beta = 0.275$; $p < 0.001$ which indicates the perceived value has positive effect on the intention to adopt AM technology. Similarly the variables perceived outside support (POS) with ($\beta = 0.364$; $p < 0.001$), external pressure (EP) with ($\beta = 0.235$; $p < 0.001$), top management support (TMS) with ($\beta = 0.241$; $p < 0.01$) and organizational readiness (OR) with ($\beta = 0.127$; $p < 0.05$), all have positive impact on the intention to adopt AM technology. The variable perceived cost (COST) has negative coefficient and p- value of - 0.162 and $p < 0.05$ respectively which shows the perceived cost of AM technology negatively affects the intention to adopt it. All these results comply with the proposed hypotheses. Therefore the hypotheses H1, H3, H4, H5, H6 and H7 are supported. On the contrary from Table 21 there is no positive relationship between perceived compatibility of AM technology with intention to adopt. The result which is $\beta = -0.033$; $p > 0.05$ shows it is in contrary to the proposed hypothesis H2. So the hypothesis H2 is not supported

Table 21 Structural Model Path Analysis

Hypothesis	**Relationship**	**β-value**	**S.D**	**T-Value**	**P-value**	**Decision**
H1	PV -> AM	0.275	0.080	3.428	0.000	Supported
H2	PC -> AM	-0.033	0.060	0.553	0.290	Not supported
H3	COST -> AM	-0.162	0.077	2.105	0.018	Supported
H4	TMS -> AM	0.241	0.076	3.176	0.001	Supported
H5	OR -> AM	0.127	0.063	1.998	0.023	Supported
H6	EP -> AM	0.235	0.070	3.353	0.000	Supported
H7	POS -> AM	0.364	0.077	4.703	0.000	Supported

Note: **PV**: Perceived value; **PC**: Perceived Compatibility; **COST**: Perceived Cost; **TMS**: Top Management Support; **OR**: Organizational Readiness; **EP:** External Pressure; **POS** :Perceived Outside Support; **AM** : Intention to adopt AM

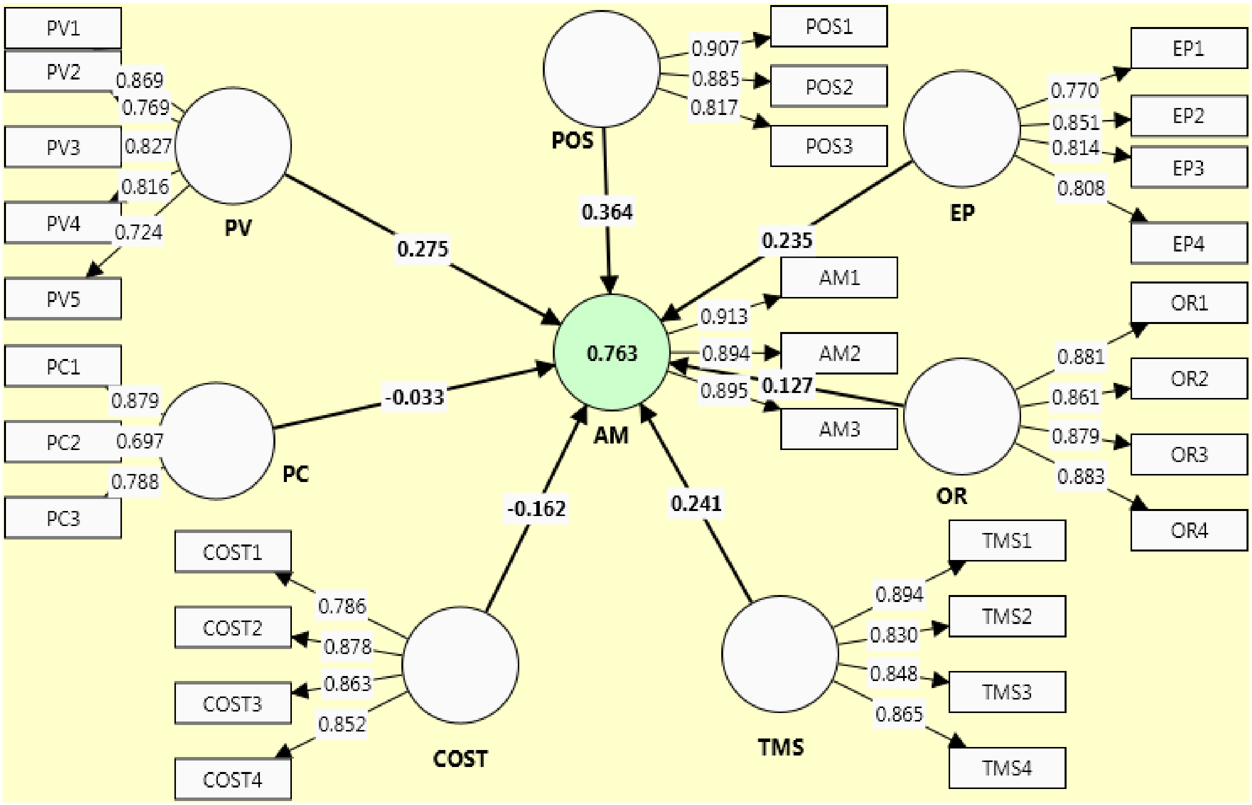

Figure 10 Estimated Structural Equation Model (Path coefficients)

<u>Note:</u> PV: Perceived value; **PC**: Perceived Compatibility; **COST**: Perceived Cost; **TMS**: Top Management Support; **OR**: Organizational Readiness; **EP:** External Pressure; **POS**: Perceived Outside Support; **AM** : Intention to adopt AM

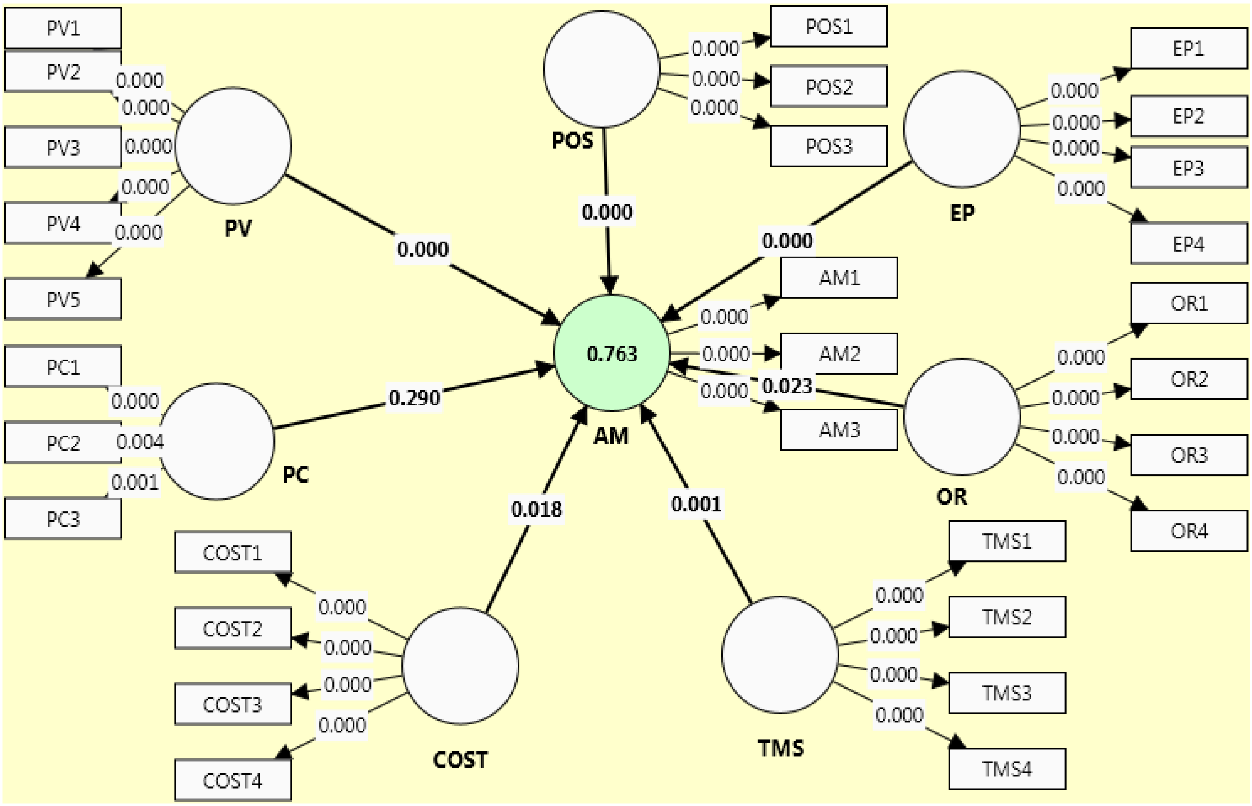

Figure 11 Estimated Structural Equation Model (P-values)

<u>Note:</u> **PV**: Perceived value; **PC**: Perceived Compatibility; **COST**: Perceived Cost; **TMS**: Top Management Support; **OR**:Organizational Readiness; **EP:** External Pressure; **POS**:Perceived Outside Support; **AM**: Intention to adopt AM

4.5 <u>Results and Discussions</u>

From the results of the path analysis, the perceived value (PV), (β =0.275; p< 0.001) and the perceived outside support (POS), (β =0.364; p< 0.001) have more positive significant effect on the intention to adopt AM technology among the seven adoption determinants studied. When people perceive the value of new technology and believe it will help them achieve their goals, they are much more likely to adopt it. People may avoid uncertainty and potential risks about new technology. So they need badly outside support to adopt, use and maintain the technology. Next factors that have significant effect on the intention to adopt AM is the variables external pressure (EP), (β = 0.235; p< 0.001), and top management support (TMS), (β =0.241; p< 0.01). Company are obliged to introduce new technology to maintain market competitiveness. So the pressure to adopt new technology comes from competitors and customers who want customized and unique products. Top management support is important in promoting and initiation of adopting technology since the management body plays a decisive role whether a technology is to be adopted or not. The next variable is the organization readiness (OR) which has a moderate positive effect ($\beta = 0.127$; $p < 0.05$) on the adoption intention. The variable perceived cost (COST) has a negative significant effect (-0.162 and $p < 0.05$) on the adoption as it is expected since the more a technology is costly the more unlikely going to be adopted by companies.

4.5.1 Technological Factors

Perceived Value

Among the technological factors, when it comes to the Perceived value(PV) of the AM technology adoption, bigger part of the respondents were able to recognize and agree on a common one that is the value to be created by AM technology. When people perceive the value of new technology and believe it will help them achieve their goals, they are much more likely to adopt it. As a result, the outcome of the path analysis indicated a significant direct effect of perceived value on AM Adoption ($\beta = 0.275$; $p < 0.001$). This result is in line with the findings of previous studies by Chatzoglou et al. (2019); Kulkarni et al. (2021) and Bag et al. (2023). Particularly, the respondents indicated on the capability of AM that can bring about the reduction of operational cost, build lightweight & complex products, enables reduction & simplification of manufacturing steps, customized production, short product delivery time and rapid prototyping process for new product development which would gain for their company competitive advantage over competitors' ones. Put differently, the implementation of AM technology empowers organizations to react to the constantly changing needs of the customers and fulfill their demands for customized designs, which are frequently intricate, challenging to replicate, or unfeasible to accomplish using other technologies.

Perceived Compatibility

According to the literature the compatibility factor is the extent to which the technology adopted satisfies the adopters' needs, values, and prior technological experience. In terms of Perceived Compatibility(PC), the result of the path analysis ($\beta = -0.033$; $p > 0.05$) shows in contrary to the proposed hypothesis that perceived compatibility of the AM technology has no any impact on the intention to adopt AM technology which contrasts with theories and studies of Rogers (2003): Ramdani & Kawalek (2009) ; Oliveira & Martins (2011); Handfield et al. (2022) . But the outcome aligns with that of Maroufkhani et al. (2020) and Chatzoglou et al. (2019) which they found compatibility has no effect on the technology adoption. The reason could be that the respondents believe that their companies can make necessary adjustments and changes within existing system, procedures, practices and values that enable them to be more flexible and compatible in order to adopt AM technology easily. In such scenario the compatibility between current practices and the AM technology adoption is not a major concern. Thus from these and from previous conflicting findings, it can be learned that the construct perceived compatibility could have positive effect or not on adoption depending on the context and respondents perceptions in which the study is carried out.

Perceived Cost

The Perceived Cost (COST) was found to affect negatively ($\beta = -0.162$; $p < 0.05$) on AM adoption which it is in consistent with the proposed hypothesis and findings of (Ghobakhloo & Ching, 2019). The respondents noted that AM technology would be costly to implement as it shown from the statistically negative significant result from the analysis. Companies decline to adopt new technology if they perceive that the technology incurs high investment cost than they are able to offer or if they think the technology is not financially worth. The respondents feel that the cost of the AM technology could be costly and they indicated that this factor would negatively influence their intention to adopt the technology as it is evident from the path coefficients analysis. Adopting new technologies may be challenging for metal industries due to financial resources limitations thereby leading managers to demonstrate a lack of interest to adopt AM technology successfully. So the cost factor is a challenging element to which owners or managers of metal manufacturing industries are sensitive to and consider it one of the major barriers to adopt new technology.

4.5.2 Organizational Factors

Top Management Support

The impacts of top management support (TMS) on AM adoption is confirmed by the path coefficient analysis with positive significant effect on AM adoption ($\beta = 0.241$; $p < 0.01$). Since the top management body has the final say over whether to adopt or not, top management support is usually found to be crucial. The key decision-makers in the metal manufacturing sector are the owners and managers; their outlook and mindset dictate how much encouragement and support AM adoption receives. The adoption and spread of technology within the company can be aided by the backing of upper management by being interested in AM technologies and initiating and promoting for its adoption. In other words, top management members are vital elements for creating a supportive ecosystem to adopt new technologies (Asiaei & Rahim, 2019).

Organizational Readiness

The moderate linkage ($\beta = 0.127$; $p < 0.05$) between organizational readiness (OR) and the adoption of AM is consistent with findings from earlier researches on the adoption of technology in other industries (Kandil et al. 2018; Lai et al. 2018; Ramdani et al. 2013). Adopting AM in the metal manufacturing industry is difficult without sufficient financial, human, and technological resources. As it is also learned from the interview conducted with senior members that there is no willingness, adequate budget and skilled personnel for adopting new technology in the current metal manufacturing industries and that is why the respondents give the importance of organization readiness on AM technology adoption.

4.5.3 Environmental Factors

External Pressure

An external pressure (EP) plays a substantial role in adopting AM technology among metal industries as it is shown from the path coefficient analysis with significant value of ($\beta = 0.235$; $p < 0.001$). Also this finding aligns with previous studies by Handfield et al. (2022); Maroufkhani et al. (2020); Chatzoglou et al. (2019). This factor is given more emphasis after the variables perceived value (PV) and perceived outside support (POS) as it is shown from the empirical analysis result. Metal industries perceiving more pressure from their environment to produce customized and intricate products for customers are more likely to decide to adopt AM technology. Companies that implement AM technology ahead of their competitors have a higher chance of maintaining their competitiveness over time than those that adopt it later. This pressure comes from government, customers, suppliers, and larger counterparts. In addition they are tempted to adopt new technology if they find that similar technology is adopted by their competitors. The findings demonstrate that environmental impositions have a major impact on AM technology, as it is learned from the interview by senior members that there is common understanding from metal industry relevant stakeholders about the importance of manufacturing locally intricate and complex parts using new technology that would replace the spare parts and components imported from abroad and add value to the customer.

Perceived Outside Support

From the analysis result as anticipated and consistent with the findings, there is a significant relationship between the adoption of AM technology and perceived outside support (POS) of AM technology adoption among SMEs. This variable is given the most emphasis by the respondents in that the positive relationship of perceived outside support with the adoption of AM technology is the most strong (β =0.364; $p< 0.001$) than that of all independent variables' effect on AM technology adoption as it is shown on the structural model path analysis Table 21. This is true that companies are sensitive when adopting or introducing new technology that they see whether the new technology to be adopted has support packages or reliable after sales service after adoption. Even companies are obliged to enter into contractual agreement or strategic relationship after adoption with the technology providers to have reliable and continuous technical support.

In summary this study has identified the variables Perceived Value, Top Management Support, Organizational Readiness, External Pressure and Perceived Outside Support as the key positive determinants for the adoption of AM technology as evidenced from the results of the empirical analysis and also is supported from previous study findings when considering adoption. As for the perceived compatibility, it does have insignificant effect on the adoption decision because companies should be flexible and make necessary changes in order to be compatible with the features and characteristics of the AM technology so that they themselves need to be compatible with the technology. Concerning the Perceived Cost the result shows negative effect on the adoption decision as proposed by the hypothesis. The cost issue will be resolved similarly if the company is financially capable to adopt the AM technology.

4.6 Benefits of AM Technology that Impact Business Performance

As it is learned from the interview conducted with some senior members who have well acquaintances with AM technology, the respondents have identified the benefits of AM technology that would provide to their company if they adopt the technology in the future.

They identified four major benefits that will have impact on their business performance. The capability of AM technology to have 1) less production cost 2) simplified and fast metal fabrication process, 3) to produce intricate and complex parts according to the needs of customers and 4) to have rapid prototype production of products for new product development. These technology capabilities will have impact on their business performance by boosting their efficiency and competitive advantage. According to Singhal et al. (2020) companies strive for both technological innovation and a competitive edge that would differentiate them from the competitors by creating highly customized and innovative products that offer unique value to the customer.

The respondents' reflection is supported by two competitive theories that help explain how organization can have competitive advantage over its competitors in the market by enhancing its internal capability through adopting new technology in addition to having other resource capabilities. A company can achieve a number of benefits from adopting new technology, including lower production costs, shorter lead times or production processes, quicker machine setup times, lower energy and labor costs, and better utilization of raw material - all of which are indicators of increased operational efficiency and gaining competitiveness.

Another point that would support the claims of the respondents is the findings of the study done by Hwang and Kim (2022). Hwang and Kim (2022) have shown in their study to compare the technical efficiency of small and medium enterprises (SMEs) that adopted emerging technologies in their production process to that of non-adopters. Their empirical findings showed that adopters' technical efficiency was higher by more than 26% to that of non-adopters after controlling both observed and unobserved factors. Even though the majority of earlier researches focused on ICT adoption regarding efficiency, they justify the existence of positive correlation between efficiency and technology adoption.

Another observation noted by the researcher and as informed from the interviewee is the current metal fabrication process existing in metal industries. To produce one part or component first the raw materials need to be reduced to the required size. After sizing the work piece it goes through various machines to produce the final product. This process can involve cutting, drilling, turning, milling, casting, etc . Such processes incur material wastage, longer process time and more energy. So they stressed that if AM technology is adopted in their company, such processes will be avoided noting that their productivity will be definitely improved with more product values created to the customer and boosting customer satisfaction. This is also reflected in the literature that AM technology avoids conventional manufacturing processes and produces parts in one machine within relatively short time (Handfield et al., 2022; Sonar et al., 2020; Attaran, 2017; Oettmeier & Hofmann, 2017).

So the Ethiopian metal manufacturing industries need strategy to become efficient and competitive in the market. One strategy to increase a company's competitiveness is to embrace innovative manufacturing technologies and compete through operational excellence which proves the positive correlation between advanced manufacturing technology and business competitiveness (Sonar et al., 2020). Furthermore, the more capable a firm is of identifying new technology, new markets, resources, and combination opportunities, the more likely it is to compete with others in those areas (Collis et al., 2021).

In summary the major benefits of AM technology that can have impact on business performance as noted by the respondents are:

1. Production cost reduction
2. Short set up and production process time
3. More product flexibility and unique features
4. Easy product customization
5. Simple fabrication process

4.7 Challenges of Adopting AM Technology

When asked, apart from the numerous benefits, respondents have identified certain challenges that they will come across when they want to integrate AM technology into their operations. One of the biggest challenges is lack of technology adoption strategy in their organizations. Due to this Ethiopian companies are lagging in adopting AM technology. This claim is also supported by Cirera et al. (2023). According to him the prevalence and adoption of AM technology among Ethiopian firms are rare. The other challenge is lack of practical exposure about AM technology. One reason for this could be due to the geographical barrier that AM technology is currently being known and adopted widely in developed world and most of the research articles on AM technology are conducted in the same area.

The other challenge mentioned by the respondents is the cost of implementing AM technology as it is confirmed from this studies empirical analysis result. Currently this opinion is true. But the cost of 3-D printers will go down as more manufacturers enter the market and as technological advancements continue (Attaran, 2017).

Lack of organizational readiness for adopting new technology is also indicated due to inadequate budget and organizational culture's lack of interest towards new technology. In addition they have mentioned that every management body is very late in decision to embrace new technology due to the wide attitude and belief that new technology has its own potential risks even though adopting the technology is beneficial for the company. The respondents mentioned that generally most management members feel insecure and uncertain about adopting new technology despite positive image of AM technology and such claim is supported by many studies (Tamvada, et al., 2022). The other point mentioned is the intellectual rights issue even if the company decides to implement the technology. For this vendors are selective when providing such technology fearing that their intellectual rights will not be protected and this makes the technology adoption late.

The last challenge mentioned is AM technology suppliers' support issues. Getting after sales service after the technology is procured will be a major challenging issue due to geographical barrier and the high cost of servicing the equipment. The other vendors' challenge is the supply of raw material for AM technology. This raw material which is in powder form could be a challenge of getting easily due to high cost and unavailability locally.

Summary of the potential challenges identified by the respondents are:

- Lack of technology adoption strategy and policy
- Lack of in-house expertise and awareness about AM technology
- Cost of implementing AM technology
- Inadequate budget for new technology adoption
- Organizational culture and resistance to accept new technology
- Obtaining after sales service or vendor support
- Feeling uncertain and insecure about the technology
- Challenge in getting the raw materials

4.8 Proposal for the Implementation of AM Technology

Introduction

Scholars argue that manufacturing technology innovation can be used strategically as a potent weapon in the competition for market share. They stressed that innovation can be leveraged for many other strategic goals in addition to cutting costs, such as improving quality, reducing delivery times, cutting inventories, saving money on equipment purchases, accelerating the development of new products, and creating new production economics. Moreover, they suggested that technology could be the primary factor influencing significant shifts in market share (Mellor et al. ,2014).

This proposal addresses the need for an implementation framework to direct the efforts of current and prospective stakeholders who are embracing this innovative manufacturing technology in order to create high-value products and open up new business prospects.

For the past 20 years, AM technology has been applied mainly for prototype production for new product development. However nowadays this technology is widely applied commercially.

This proposal attempts to give insights about elements that affect the implementation of AM technologies because of their resource needs, advantages and disadvantages, and other aspects.

Before further detail, it is important to see and understand briefly the manufacturing process and the advantages of AM technologies mentioned in literature review section of this study.

AM process has the following sequence

- Design using CAD
- Changing to STL format
- Transferring the STL file to AM machine
- Setup of the Machine
- Manufacturing
- Part removal and post-processing

The advantages of AM production are

- Cost reduction
- Improved material usage
- Less energy consumption
- Less waste production
- Design optimization
- Short set up and processing time
- Improved product quality
- More product flexibility and unique features
- Easy product customization
- Short delivery time

<u>Strategic Elements</u>

The market and the features of the product must be taken into consideration when choosing whether to invest in AM technologies. Any investment in technology must be supported by high capacity utilization. If a process is not going to be heavily utilized on one product, it must satisfy the business and manufacturing requirements of other products. Numerous product attributes have been proposed by authors in the field of AM management, and these attributes influence the kinds of products that are appropriate for AM production. In general, the attributes of the product are as follows (Mellor et al., 2014).

- Customization of products
- Design optimization of products for additional functionality
- Products of low volume.

Bringing the business, manufacturing, and R&D strategies into strategic alignment must come before AM implementation. The advantages of technology must be connected to the skills needed by the manufacturing facility, skills that come from the business plan, which is seen as the market-pull approach to AM implementation. It is also suggested that investing in AM could be seen as a structural move that will develop new manufacturing capabilities and open up new business avenues for the company- a technology-push strategy—in keeping with the company's current resource-based perspective (Mellor et al., 2014).

Operational Elements

An organization's operational and administrative structures will alter in response to changes in its technology. Product design is one area of operations where a lot of authors have suggested that the use of AM will change things significantly. Many scholars have discussed how AM affects product design and designers themselves.

Many of the limitations imposed by traditional manufacturing(TM) processes are not applicable to AM due to its additive nature. These unique characteristics of AM systems necessitate the development of new design tools and practices. It is suggested that designers' comprehension of the new design for AM constraints will impact how AM is implemented.

Production scheduling and quality control are two more areas of operations that the adoption of AM is likely to significantly alter. Regarding the true cost of implementing and running the AM system, there is a large knowledge gap. Previous research has identified four major cost factors for additive processes: labor, machine, material costs and operation times (Mellor et al., 2014).

Since AM technology cannot currently create net-shaped parts, post-processing (such as support removal, heat treatment, etc.) is necessary. Consequently, it is proposed that the success of implementation depends on AM's integration with a supportive production system.

Supply Chain Elements

The application of AM involves the intersection of two supply chains. The first one runs from equipment vendors to technology purchasers. Second, suppliers and customers will be impacted as the buyer incorporates the technology into their own supply chain (Sobota et al., 2021). Big organizational changes are required for new process technologies to realize their full potential. These changes include reorganizing supplier relationships to become more collaborative.

It is suggested that supplier and customer cooperation will be necessary for the manufacturing of AM technologies. It is well known that a key element in the success of implementation is vendor support throughout the process. Studies have indicated a clear connection between technological innovation's complexity and the intensity of user-supplier interaction processes. Thus, it is suggested that a crucial component of AM implementation is vendor support (Chatterjee et al., 2023). One noteworthy aspect of the modern AM industry is the tendency of machine manufacturers also to serve as suppliers of raw materials (like powders) after their machines are put into service. This feature is partially caused by the technology's immaturity (as there are few material suppliers), and additionally, it's probably a tactic by the machine supplier to protect future business. Decisions about where to locate manufacturing will also need to be made because, in theory, all that is required for production are raw materials and CAD data. The elimination of tooling may make it possible to locate manufacturing based on customer needs (Niaki et al., 2019).

Organizational Elements

Research has demonstrated that an organization's size and maturity affect how well it understands the process of implementing new manufacturing technology. Several academics have contended that small businesses differ from larger ones and that, due to their smaller size and level of maturity, the theories developed for larger companies may not apply to smaller ones (Govindan & Arampatzis, 2023). As a result, an SME's implementation strategy will probably differ from that of a big company. Related to size, research on the application of new manufacturing technologies indicates that an organization's organizational structure is critical to the effective application of manufacturing technology.

It is proposed that in order for AM technologies to be successfully adopted, decisions about their adoption will need to be made in conjunction with changes to jobs and tasks, which will require adjustments to work structures, procedures, and practices.

Organizational culture, which is related to structure, describes the intricate web of knowledge that members of an organization utilize to carry out tasks and produce social behavior. The company culture and how it adapts to AM manufacturing may experience the greatest, yet least understood, impact (Mellor et al., 2014).

Thus, in order to use AM processes as a manufacturing technology, designers and engineers need to reevaluate design for manufacturing. Users of AM must understand the capabilities of new technology processes and match products with the process. Therefore, it is also suggested that a crucial component of AM implementation is the experience and skill of the workforce.

Technological Elements

To obtain a competitive edge from the application of AM, it has been underlined that the adopting organization must be able to match the advantages of technology to the business strategy. AM technologies offer a variety of technological advantages. As it is mentioned in literature review section and this study's empirical analysis result the perceived value, the perceived compatibility and the perceived cost of the technology should be considered and evaluated before implementing the technology. The adopting company must, however, also be aware of the trade-offs associated with utilizing new manufacturing technology. For instance, the AM process still has a restricted material range, expensive machinery and material costs, and relatively sluggish process speeds (Mellor et al., 2014).

The absence of technical guidelines, regulations and standards is another significant obstacle to adoption. It is likely that some of these AM characteristics arise from the technology not reaching maturity. Therefore company owners and managers should consider this when determining whether to adopt or not.

The effectiveness of implementation of AM technology will depend on adopting organizations' capacity to communicate the advantages of the technology as a manufacturing process in an unbiased and transparent way.

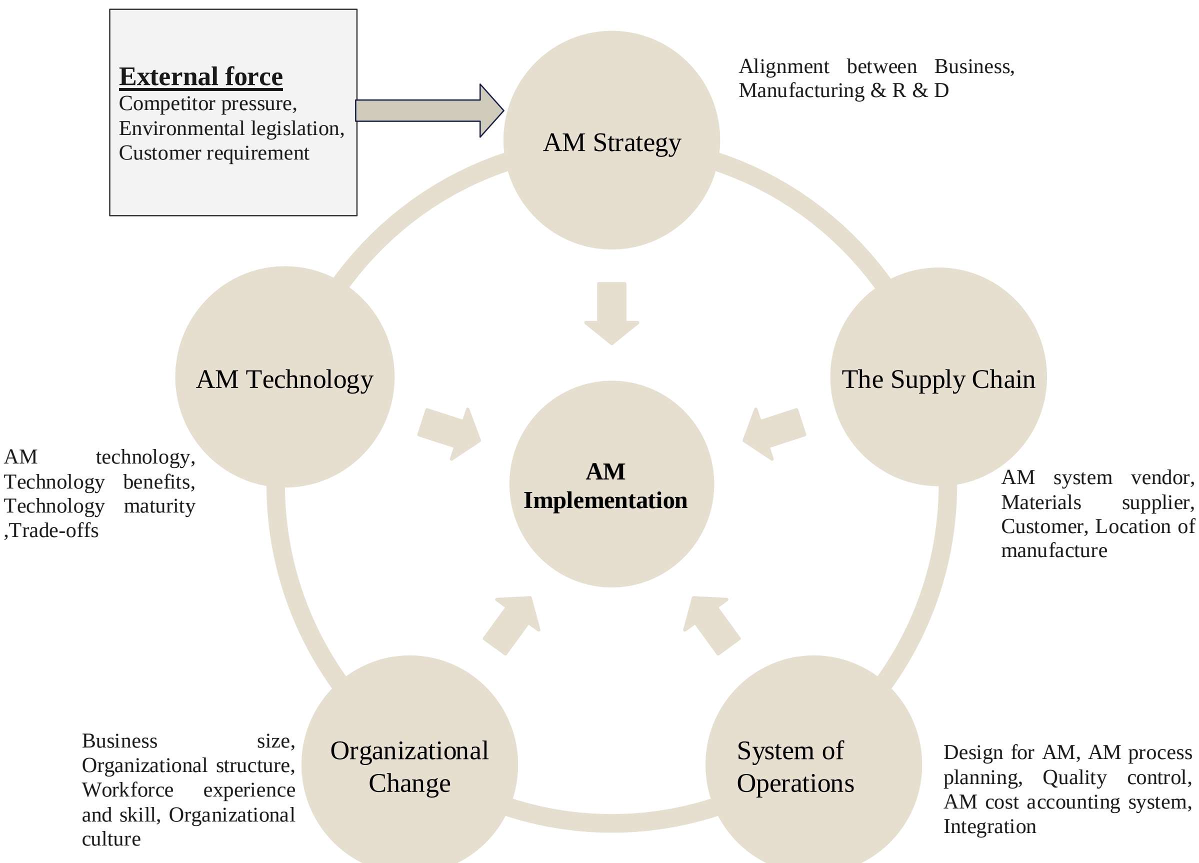

Figure 12 Frame Work for Implementation of AM technology (Source: Mellor et al.,2014)

CHAPTER 5

5. Conclusion and Recommendation

5.1 Conclusion

The chapter provides a summary of the theoretical and empirical research findings regarding the determinants influencing AM technology adoption, its business impact and adoption challenges. The chapter identifies the research limitations and discusses the managerial implications of the findings. The chapter concludes with suggestions for additional research.

The study is centered mainly on Ethiopian metal manufacturing industries. Concerning the level of adoption of AM technology in Ethiopia, the current manufacturing industries can be classified either as not adopters or laggards as indicated by Cirera et al., (2023).

Over the last two decades, AM technology, more specifically, 3DP technology has advanced quickly from prototyping to a potent manufacturing tool that currently powers an entire manufacturing industry.

The Ethiopian metal manufacturing have been affected long by low efficiency due to low productivity, obsolete machinery and equipment and low technological capability. Hence, this sector needs to embrace innovation and new ways of metal manufacturing process through AM technology

The study is centered on the technological, organizational, and environmental (TOE) innovation adoption model. This model is selected because it encompasses the tenets of most of the adoption theories developed before it and is widely used by scholars studying technology adoption. The study employed two approaches. Quantitative and qualitative approaches. The quantitative study is based on the empirical analysis to test the proposed hypotheses with the intention of identifying the determinants that substantially affect the decision to use AM technology. The qualitative one is based on interview with the aim of identifying the business impacts and the challenges of adopting the technology. Accordingly questionnaires, interviews and factory observation are employed to gather the data. The study revealed that adoption decisions of the AM technology are impacted by a range of technological, organizational, and environmental factors and this study has identified the variables perceived value, top management support, organizational readiness, external pressure and perceived outside support as the key positive determinants for the adoption of AM technology as evidenced from the results by the empirical analysis. These results are also in line with the findings of previous researches. Out of these determinants, the perceived outside support and perceived value have the most positive significant influences on the adoption decision of AM technology. As for perceived compatibility, the result shows that this variable has insignificant effect on the adoption decision in contrary to the proposed hypothesis. Concerning the perceived cost the result shows negative influence on the adoption as proposed by the hypothesis. The proposed conceptual model fits well as the independent variables jointly explains significantly (76.3 %) the adoption decision.

The study indicated various benefits of AM technology but respondents have recognized, operational cost reduction, improved material usage, complex product design, short delivery time, simple metal fabrication process and high customization as major benefits. The respondents have also identified two major elements of AM technology applications that can enhance their business performance if the technology is adopted within their organization that are1) improvement in productivity and 2) value creation to the customer.

The challenges faced as noted by the respondents for adopting AM technology are lack of technology adoption strategy and policy, low organizational readiness, insufficient in-house expertise and low awareness about the benefits of AM technology, high implementation cost, uncertainty and feeling insecure about the technology and its vendor support.

Finally framework is provided for the implementation of AM technology within the perspectives of company strategy, supply chain, operational, organizational, technological and environmental elements.

5.2 Recommendations

- The variables perceived value, top management support, organizational readiness, external pressure and perceived outside support are key determinants that influence most the decision to adopt AM technology as evidenced from the results of the empirical analysis. In addition to these, other technological, organizational, and environmental (TOE) factors need to be considered in the analysis and decisions for AM technology adoption in future studies.
- The issues of variables perceived compatibility and cost can be resolved if the technical and financial readiness of the company is high which can be achieved through having organizational change and flexibility that makes the company compatible and allocating adequate financial resources for the investment cost of the technology. So both compatibility and cost factors need

not to be considered as major issues for adoption if the benefit of the technology outweighs. So this needs cost and benefit analysis.

- Companies need to have technology adoption policy, strategy and plan that align with their organization's strategy and objective. Unless they embrace new technology, their survival will be in danger. Due to this fact this study recommends for the metal manufacturing industries and other sector to adopt AM technology.
- Companies need to have high organization readiness in terms of financial, human resources infrastructure, culture and values to accept AM technology.
- Before deploying AM technology, companies should evaluate their product portfolio, business strategy, and any operational difficulties they may be experiencing. Efficiency analysis may be done to determine which operations are becoming inefficient and which production techniques and processes will provide the greatest value for the end consumer. This is realized through having appropriate adoption strategy where the planning, implementation and performance and evaluation stages of the adoption process are clearly and properly defined.
- The challenges of AM technology need to be evaluated properly before adopting it in order to become fully prepared and to minimize the potential risks.
- Strategic partnership is important with AM technology vendors to facilitate its adoption and to get the necessary support after implementation. So a company should have sound procurement strategy that considers the mutual benefits of both parties when adopting the technology.
- African countries like South Africa, Morocco, Tunisia, Nigeria and Egypt, where there is high level of commercial applications, awareness, extensive training and education on additive manufacturing technology are good models to follow.

5.3 Research Limitations

There were limitations on this study. The representativeness of the sample size is the first research limitation. Being small sample size the result cannot be generalized. Second limitation is the limited no of hypotheses or factors that affect the decision to adopt AM technology. Control variables are not considered. Also due to this the result cannot be generalized.

5.4 **Recommendations for Further Research**

The findings of this research need to be verified with large sample size and also with other industrial sectors. Other variables need to be incorporated in future study by researchers to make the results of the study more comprehensive, conclusive and general.

5.5 **Managerial Implications**

This study will have its managerial implications especially for countries like Ethiopia where the metal manufacturing industries are driving the national economy which are under performing on the local and global market.

The main objective of this study is to provide academics, business people, and policymakers with insightful information about the determinants that influence its adoption and the benfits of the technology. This will enable them to implement the necessary initiatives or policies that are essential for the technology to be adopted successfully.

The second one is to raise awareness of AM technology as a technological advancement and its potential for metal manufacturing industries success.

Thirdly, by identifying the areas where AM technology can add the greatest value, this research hopes to assist all new adopters. In this regard, companies should determine their business strategy, product portfolio, and any operational challenges they face before implementing AM technology.

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<u>Annex -1 Research Questionnaires</u>

Addis Ababa University
Addis Ababa Institute of Technology
School of Mechanical and Industrial Engineering
Post Graduate Program in Industrial Engineering

<u>Purpose of the Questionnaire</u>

Dear Sir/ Madam,

This questionnaire is designed to collect relevant data for my research thesis entitled as '**The Determinants and Business Impact of Additive Manufacturing Technology Adoption: The Case of Ethiopian Metal Manufacturing Industries**'

The general objective of this research is to explore factors that determine the adoption of additive manufacturing (AM) or 3D- metal printing technology and its impact on the business of Ethiopian metal manufacturing industries. Moreover it will assess the challenges of adopting additive manufacturing (the 3D-metal printing technology). Upon completion, the outcome and significance of this research will be mainly

1. It will provide valuable insights about the determinants that determine for adopting additive manufacturing (AM) technology in Ethiopia
2. It will show the importance of adopting additive manufacturing (AM) not only attractive for prototype production but also for commercial and industrial purposes.
3. It will show the potential business impacts and challenges of additive manufacturing (AM) technology if it is adopted in Ethiopia.

Hence, the researcher needs the utmost attention and collaboration of all concerned persons who are selected to fill this questionnaire in providing reliable and genuine information that could help to reach the right research outcome and conclusion. The data that you will provide is very important for the achievement of the research objectives. Therefore, I would like to request you kindly for your genuine and honest responses. As a matter of ethical research, I solemnly committed that your response would be kept confidential and it will be used only for research purpose.

<u>Note</u>: Additive manufacturing technology (AM) means in other words 3D-metal printing technology

I thank you so much in advance.
Sincerely Yours,

Amanuel Haile (Industrial Engineering Post Graduate Student, AAiT, AAU)

Address:Email: amanuelht@yahoo.com, Tel.: 0911669224

Part I General Information:

1. Name of your current organization____

2. Organization location: (City or Region)______________________

3. Kindly indicate your responsibility that describes your role in the organization

   ____

4 For the above mentioned responsibility, please specify your department

   ----

5 Please indicate your gender. Male □, Female □

6. Please indicate your age: Below 25 yrs : □, 25 to 34 yrs : □, 35 to 44 yrs : □, 45 to 54 yrs :□, 55 to 60 yrs :□, above 60 yrs : □

7. Please indicate your highest level of professional education obtained so far.

   PhD : □, Master's degree:□, Bachelor degree:□, Diploma:□, Certificate:□, High school: □

   Others (please specify……………………………………….)

8. Please indicate your educational background _____________________________

9. Please indicate your total work experience.

   Below 3 yrs : □ , 3 to 5 yrs : □, 6 to 10 yrs : □, 11 to 15 yrs: □ , Above 15 yrs :□

10. Please indicate your experience in the current organization

   Below 3 yrs : □ , 3 to 5 yrs : □, 6 to 10 yrs : □, 11 to 15 yrs: □ , Above 15 yrs :□

<u>Part II. Questionnaires</u>

The following are determinants or factors for adopting Additive Manufacturing (AM) technology (3D-Metal Printing) in Ethiopian metal manufacturing industries. Please rate each item by using scales of 1, 2, 3, 4, 5, 6 or 7 points depending on the degree of your agreement with each factor. The rating points are ranked according to the following.

1= Strongly Disagree, 2 = Disagree, 3 = Somewhat Disagree, 4=Neutral, 5= Somewhat Agree, 6=Agree, 7= Strongly Agree.

So choose one of them and put your mark (√) in the appropriate box

Determinants for Adoption of Additive Manufacturing		**Seven Scale Rating**						
1. Technological Context								
Perceived Value		1	2	3	4	5	6	7
PV 1	AM reduces operational cost							
PV 2	AM can build lightweight & complex products							
PV 3	AM enables reduction & simplification of manufacturing steps							
PV 4	AM enables customized production							
PV 5	AM enables rapid prototyping process for new product development							
Perceived Compatibility		1	2	3	4	5	6	7
PC1	AM is compatible with existing manufacturing system							
PC2	AM is consistent with the organization's business practices and needs							
PC3	AM fits with the organization's behavior and culture							
Perceived Cost		1	2	3	4	5	6	7
COST1	Learning to use AM technology incurs more cost for companies							
COST2	AM technology incurs high implementation cost							
COST3	AM technology incurs high cost to maintain							
COST4	AM technology after sales service is costly							

2. Organizational Context								
Top Management Support		1	2	3	4	5	6	7
TMS1	Top management creates support for AM adoption							
TMS2	Top management initiates the use of AM technology in the organization							
TMS3	Top management promotes the use of AM technology within the organization							
TMS4	Top management is interested in adopting AM technology							
Organizational Readiness		1	2	3	4	5	6	7
OR1	Company's structure, system and culture prevents us from adopting AM technology							
OR2	Lacking capital/financial resources prevents us from adopting AM technology							
OR3	Lacking skilled manpower prevents the business from adopting AM technology							
OR4	Lacking proper infrastructure prevents us from adopting AM technology							
3. Environmental Context								
External Pressure		1	2	3	4	5	6	7
EP1	Our choice for adoption of AM technology would be influenced by our competitors that use the technology							
EP2	Our company would adopt AM technology in response to what competitors are doing							
EP3	Our company is under pressure from competitors to adopt AM technology							
EP4	Our company is under pressure due to volatile customer needs for various and new products							
Perceived Outside Support		1	2	3	4	5	6	7
POS1	Local agencies/ suppliers can provide required training							

	for AM adoption							
POS2	Local agencies/suppliers can provide effective technical support for AM technology adoption							
POS3	Local agencies/suppliers actively market AM technology adoption							
AM Adoption Intention		1	2	3	4	5	6	7
AM1	We plan to adopt AM technology in the future							
AM2	We intend to encourage others to Adopt AM technology							
AM3	We intend to be informed about AM technology and use them in the future							

Part III Questions for Interview (On Benefits , Business Impact and Challenges of AM)

Interview (to be conducted for senior members of MTEIRDC staff only)

1 What is the main goal or purpose of conducting research and development activities in your company?

2 Do you have strategy and plan for new technology adoption?

3 Do you use Additive Manufacturing technology (3D -printing) for metal fabrication process?

4 What is your impression or reflection if Additive Manufacturing technology (3D -printing) is adopted for metal industries in our country?

5 Do you think Additive Manufacturing technology (3D -printing) has benefits and positive impact on your company business if it is adopted. Yes or No? If the answer is YES, what are the benefits and their business impact? Please detail them

6 What are the potential challenges you may face if your company plans or decides to adopt Additive Manufacturing technology (3D -printing)? Please detail them

7 What are the major problems faced currently by metal manufacturing industries in our country?

Annex-2: Structural Equation Modelling (SEM) Result Using SmartPLS

Correlation

Variable	AM	COST	EP	OR	PC	POS	PV	TMS
AM	1.000	0.601	0.706	0.578	0.154	0.738	0.681	0.708
COST	0.601	1.000	0.652	0.490	0.076	0.564	0.680	0.658
EP	0.706	0.652	1.000	0.503	0.256	0.557	0.583	0.656
OR	0.578	0.490	0.503	1.000	0.013	0.460	0.441	0.516
PC	0.154	0.076	0.256	0.013	1.000	0.203	0.093	0.157
POS	0.738	0.564	0.557	0.460	0.203	1.000	0.530	0.570
PV	0.681	0.680	0.583	0.441	0.093	0.530	1.000	0.554
TMS	0.708	0.658	0.656	0.516	0.157	0.570	0.554	1.000

Reliability and Validity

Variable	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
AM	0.884	0.887	0.928	0.812
COST	0.867	0.870	0.909	0.715
EP	0.826	0.829	0.885	0.658
OR	0.899	0.905	0.930	0.767
PC	0.711	0.774	0.833	0.627
POS	0.839	0.848	0.903	0.757
PV	0.861	0.866	0.900	0.644
TMS	0.882	0.884	0.919	0.739

Discriminant Validity (HTMT)

Variable	AM	COST	EP	OR	PC	POS	PV	TMS
AM								
COST	0.685							
EP	0.822	0.770						
OR	0.644	0.546	0.580					
PC	0.179	0.148	0.338	0.090				
POS	0.853	0.658	0.668	0.533	0.269			
PV	0.778	0.780	0.685	0.498	0.134	0.617		
TMS	0.798	0.749	0.765	0.581	0.191	0.654	0.630	

Discriminant Validity (Fornell-larcker)

Variable	AM	COST	EP	OR	PC	POS	PV	TMS
AM	0.901							
COST	0.601	0.846						
EP	0.706	0.652	0.811					

OR	0.578	0.490	0.503	0.876				
PC	0.154	0.076	0.256	0.013	0.792			
POS	0.738	0.564	0.557	0.460	0.203	0.870		
PV	0.681	0.680	0.583	0.441	0.093	0.530	0.803	
TMS	0.708	0.658	0.656	0.516	0.157	0.570	0.554	0.860

Collinearity (VIF)

Variable	**VIF**
AM1	2.628
AM2	2.457
AM3	2.432
COST1	1.736
COST2	2.362
COST3	2.615
COST4	2.480
EP1	1.639
EP2	2.028
EP3	1.795
EP4	1.750
OR1	2.495
OR2	2.527
OR3	2.633
OR4	2.738
PC1	1.520
PC2	1.368
PC3	1.347
POS1	2.438
POS2	2.267
POS3	1.667
PV1	2.507
PV2	1.772
PV3	2.172
PV4	2.016
PV5	1.529
TMS1	3.120
TMS2	1.962
TMS3	2.540
TMS4	2.259

Factor Loading

Variable	AM	COST	EP	OR	PC	POS	PV	TMS
AM1	0.913							
AM2	0.894							
AM3	0.895							
COST1		0.786						
COST2		0.878						
COST3		0.863						
COST4		0.852						
EP1			0.770					
EP2			0.851					
EP3			0.814					
EP4			0.808					
OR1				0.881				
OR2				0.861				
OR3				0.879				
OR4				0.883				
PC1					0.879			
PC2					0.697			
PC3					0.788			
POS1						0.907		
POS2						0.885		
POS3						0.817		
PV1							0.869	
PV2							0.769	
PV3							0.827	
PV4							0.816	
PV5							0.724	
TMS1								0.894
TMS2								0.830
TMS3								0.848
TMS4								0.865

Path Coefficients Analysis

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
COST -> AM	-0.162	-0.156	0.077	2.105	0.018
EP -> AM	0.235	0.232	0.070	3.353	0.000
OR -> AM	0.127	0.131	0.063	1.998	0.023
PC -> AM	-0.033	-0.022	0.060	0.553	0.290
POS -> AM	0.364	0.361	0.077	4.703	0.000
PV -> AM	0.275	0.270	0.080	3.428	0.000
TMS -> AM	0.241	0.239	0.076	3.176	0.001

Annex-3: Organizational Chart of MTEIRDC,