Addictive Manufacturing Advancement in Current Manufacturing Technology:

A Case Study

By

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DECLARATION

I hereby declare that the case study is based on my original work except for quotations and citations that have been duly acknowledged. I also declare it has not been previously or concurrently submitted for any other degree at Universiti Tun Abdul Razak (UNIRAZAK) or other institution.

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Previously known as "rapid prototyping" before being renamed "additive manufacturing" to better reflect the nature of the process, it is an approach for quickly developing a representation of a system or component during the early stages of product development is known as rapid prototyping (RP). The primary goal is to develop a prototype or basic model as quickly as possible, followed by further models, and finally the finalised product. Known as rapid prototyping in the product development world, it is a term used to describe technology that can manufacture physical prototypes in a relatively short period of time. The use of this technology allows products to be manufactured directly from digital data. Many different variations of these technologies have been developed since their inception, and they are now being employed in a wide variety of applications. Users of RP technology have come to the conclusion that the label "RP" is inadequate and does not accurately describe the technology's most recent uses. A significant improvement in the quality of the output from these machines has resulted in a considerably closer interaction between the machine and the finished product. We can no longer refer to these machines as "prototypes" because they are now capable of directly manufacturing a large number of different parts at the same time. The term "Rapid Prototyping" is misleading since it ignores the most crucial component of these technologies: they all rely on additive techniques to construct their finished products. The ASTM International Technical Committee came to the conclusion that a new nomenclature should be used for the organisation. A consequence of this is that the term additive manufacturing is now used by the vast majority of international standards organisations, such as the American Society for Testing and Materials (ASTM). In addition to being known as additive manufacturing (AM), amplifier

manufacturing is founded on the idea that a model developed with a three-dimensional Computer Aided Design (3D CAD) system can be constructed immediately without the need for any process preparation. Additive manufacturing technology (AM) makes the process of making complex 3D objects directly from CAD data simpler, despite the fact that it is not as straightforward as it appears at first glance. A full analysis of the component geometry is required in order to determine things such as the sequence in which distinct features can be made, the equipment and processes that must be used, and any additional features that may be required to complete the part. For additive manufacturing, all that is necessary is a fundamental understanding of how the additive manufacturing machine works as well as the materials that are used in the item's construction. This study project assesses and advances the current state of the art in the field of additive manufacturing through debate and presentation. It is intended to be a collaborative effort between researchers and industry. This project delves into three case studies in depth, including an assessment of each event as well as the conceptual frameworks that are proposed for each example.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

As of its close link to a company's overall performance, the notion of firm competitiveness is gaining traction (Bhawsar and Chattopadhyay 2015). It is defined as a company's ability to outperform market competitors over time by providing goods and services that meet or exceed customer expectations (Ambastha and Momaya 2004; Momaya 2019; Singh et al. 2007). It evaluates a company's ability to expand into new areas, outperform competitors, and bring in additional capital (Falciola et al. 2020). One of the most pressing challenges for modern manufacturing forms is catching up with operational excellence and, as a result, expanding their domestic and worldwide market presence (Kulkarni et al. 2016, 2019).

Operational excellence through the use of modern manufacturing technology, which is becoming increasingly popular, is a new strategy for strengthening competitiveness. An empirical study was undertaken by Dangayach and colleagues to see if there is a link between sophisticated manufacturing technology and company competitiveness. According to Holmström et al. (2016), a rising number of organisations are turning to additive manufacturing (AM) as a cost-effective manufacturing technology that increases operational efficiency and, as a result, aids in the pursuit of a company's competitiveness. "In contrast to subtractive manufacturing techniques like traditional machining, additive manufacturing is the process of joining materials to produce products from 3D model data, usually layer by layer" (ASTM 2015). Additive manufacturing (AM) necessitates significant paradigm shifts in product development cycles, operating operations, and supply chain practises, in addition to enabling product personalization. Manufacturers will be able to compete in new ways as a result of this (Deradjat and Minshall 2017; Gibson 2017; Tuck et al. 2008).

1.2 Problem Statement

Several academics emphasised the need of implementing additive manufacturing into their organisations in order to increase their organisations' competitiveness and efficiency (Despeisse et al. 2017; Ivanov et al. 2019; Ryan et al. 2017). However, in order to develop competitive strategies for AM implementation, the operations manager must have extensive knowledge of the many components of AM implementation. The vast majority of manufacturing organisations are having difficulty grasping the fundamentals of additive manufacturing implementation challenges. A lack of research on the relationship between AM implementation and corporate competitiveness has been identified in the preceding literature, to our knowledge. Hence, in order to meet the strategic requirements of the company, it is necessary to identify AM implementation aspects.

1.3 Research Objectives

From both an industry and academic perspective, the purpose of this research is as follows:

1. To use accessible material to identify essential areas of AM implementation that must be considered.
2. To identify AM implementation variables from earlier research, regardless of whether the research was conducted in a specific sector or domain.
3. To validate the AM implementation variables.

1.4 Research Questions

1. How is the identification of AM implementation factors essential for the sake of meeting the company's strategic objectives?
2. What strategies can corporate leaders use to make the most of additive manufacturing technologies in order to increase their company's competitive advantage?

3. How might additive manufacturing help companies enhance their long-term production capabilities in order to compete on a global level?

1.5 Significance of Study

The diffusion of this technology, as well as the primary impediments to its acceptance, can help us gain a better knowledge of the dynamics of this industry and its competitiveness in this regard. Incorporating additive manufacturing technology into a company's operations will enable the company in generating a comprehensive list of important parameters to evaluate its relative competitiveness with its competitors. As a result, this research provides a conceptual model that outlines the major AM implementation variables that must be addressed when evaluating the competitiveness of a firm's manufacturing operations.

1.6 Organisation of Study

Chapter 1 of this research project proposes significant discussion on this research. Introduction to the study's background, problem description, research objective, research questions, and the significance of the investigation were all topics covered in this chapter's discussions.

Chapter 2 of this research project includes the literature review of this study. It starts off with an introduction, followed by the theoretical foundation, empirical research, conceptual framework, hypotheses and summary of the chapter.

Chapter 3 presents the methodology used to conduct the study that includes the research design, sampling procedure, data collection method, and analysis technique.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

"Additive Manufacturing" is the official name for what is now known as "Rapid Prototyping". It was previously known as "Rapid Prototyping" and is now widely referred to as 3D Printing. Rapid prototyping refers to the creation of prototypes in a short amount of time, usually less than a week. The term "rapid prototyping" (also known as "RP") is used in several industries to describe the process of swiftly developing a system or portion representation prior to final release or commercialization. The goal is to build something quickly and efficiently, with the end result being a prototype or basic model that may be used to produce more models and, finally, the finished product. Rapid prototyping, a term used by management consultants and software engineers to describe a process of developing business and software solutions in pieces that allows them to provide feedback during the development process, allows clients and other stakeholders to test ideas and provide feedback during the development process. The phrase "Rapid Prototyping" was commonly used in the product development industry to describe ways for creating physical prototypes straight from digital model data. This essay focuses on the later technologies, which were originally designed for prototyping but are now employed for a variety of other applications, including manufacturing.

Users of RP technology have determined that the term "RP" is insufficient and does not adequately reflect the technology's most current applications. The machine's output quality has improved dramatically, resulting in a much closer contact between the machine and the finished product. Because these machines can now immediately manufacture a huge number of distinct parts at the same time, we can no longer refer to them as "prototypes." The term "rapid prototyping" is deceptive since it leaves out the most important aspect of these technologies: they all use additive techniques to build their final products.

One of the most important concepts in additive manufacturing is that a model developed with a "three-dimensional Computer Aided Design (3D CAD) system" that can be built right away without any process preparation. Despite the fact that it is not as simple as it appears at first glance, additive manufacturing technology (AM) makes less complicated the process of creating complicated 3D things directly from CAD data. To establish factors like the sequence in which separate features can be created, the equipment and procedures that must be employed, and any extra features that may be necessary to complete the part, a detailed analysis of the component geometry is required. All that is required for additive manufacturing is a basic understanding of how the additive manufacturing machine works as well as the materials utilised in the item's development. To make items, material layers are used; each layer represents a narrow cross-section of the part derived from the original “CAD data” and is represented by a different colour. This is how the AM system works. The final component will be a close approximation of the original data because each layer in the physical world must have a constant thickness.

AM is the process of converting a computer CAD model into a real product through a sequence of processes. AM is also known as additive manufacturing. A number of additive manufacturing (AM) techniques will be used in a variety of goods in a variety of ways and to varied degrees. Smaller, simpler things may just require additive manufacturing for visualisation models; however, larger, more complex goods including considerable technical data may require additive manufacturing at several stages and iterations throughout the product development cycle. Furthermore, due to the speed with which it can generate rough pieces, additive manufacturing is extensively employed during the early stages of the product development process. Cleaning and post-processing (such as sanding, surface preparation, and painting) items before they can be utilised at a later stage of the process can be time-consuming, but additive manufacturing (AM) might aid in some circumstances by producing delicate forms without the need for tooling. It will be explored in greater depth later in this text, but to summarise, it is used in almost all additive manufacturing methods.

Additive Manufacturing (AM) technologies, which employ three-dimensional digital models to build things layer by layer, have a lot of potential for producing complex, customised parts in a short amount of time. These technologies have the potential to cut production costs and shorten time to market for innovative products and services, in addition to helping firms enhance product quality, reduce material waste, and reduce energy intensity (Janeshi, 2013; Pellegrino, Makila, McQueen, & Taylor, 2016). Additive manufacturing methods are adaptable to a wide range of technological applications, allowing them to "supplement or surpass conventional production procedures" (Kinghels, 2015). Traditional manufacturing procedures are still necessary in many applications to produce high-quality, high-performance, reliable, and repeatable products, especially where large-scale parts or enormous production volumes are required, as in aerospace and defence (Kinghels, 2015). As a result, these technologies' general acceptance and commercialization have been delayed in recent years. A number of technological difficulties must be overcome before direct part manufacture can be broadly adopted and the anticipated economic benefits of additive manufacturing realised (AM).

These challenges can be classified into four different categories: ASM (Application-Specific Modelling and Simulation), ASM (Application-Specific Materials), ASM (Application-Specific Processes and Equipment), ASM (Application-Specific Qualification and Certification), ASM (Application-Specific Qualification and Certification), ASM (Application-Specific Qualification and For analysing the basic aspects of additive manufacturing processes, such as the mechanical qualities of the things produced using additive manufacturing, it is critical to close existing knowledge gaps in measuring methodologies, performance metrics, and standards (Janeshi, 2013). If businesses want to stay up with changing client needs and market conditions, they must invest in digital capabilities. AM (additive manufacturing) is a technique that is revolutionising manufacturing and supply chain optimization. It's growing more and more popular. Additive manufacturing, also known as 3D printing, is expected to have a significant impact on the manufacturing industry because it allows for the layer-by-layer construction of molten objects at high temperatures directly from digital files generated with CAD software, resulting in increased manufacturing flexibility and decentralisation (Wohlers 2019). Traditional manufacturing procedures such as casting, forging, and machining make it impossible to construct complicated shapes out of microscopic layers of material. The production department has the capacity to override the designers' judgments because they are capable of generating any type of specialised part that the designers desire.

The products' decentralised nature, as well as their accessibility to clients, allows for item customisation both individually and in big quantities. In the future years, increased manufacturing efficiency, as well as the introduction of new and superior products made possible by additive manufacturing, will propel on-demand manufacturing forward. In order to successfully deal with this trend, it will be required (Huang et al. 2013; Verboeket and Krikke

2019). This technique of production, known as tool less manufacturing since it does not require the use of highly specialised tools as in traditional manufacturing, is gaining popularity. "Design flexibility" and "complexity is free," two of the most fundamental qualities of additive manufacturing, are two of the most important characteristics. The production cycle has been reduced, and mass customisation of the product has become more cost-effective for the customer, thanks to the elimination of a number of machining techniques from the manufacturing process. Apart from that, it may be swiftly and easily integrated into existing manufacturing processes as a complement to traditional subtractive technologies, resulting in increased efficiency.

Numerous research have shown that it may be used in a variety of applications, including aircraft, automobile spare parts, biological implants, jewellery, and tissue scaffolds, to name a few (Campbell et al. 2012; Gibson 2017). Additive manufacturing (AM) may now be used to build metallic, ceramic, polymeric, and biological items from CAD data in as little as a few days thanks to technology developments and increased industrialization. Because of advancements in materials and increased manufacturing, this is achievable. To increase the efficiency of production and assembly processes, product designers are incorporating additive manufacturing (AM) technology into their designs. Additive manufacturing (AM) technologies are now commercially available in a number of forms, and they're being used to boost manufacturing and assembly efficiency. Manufacturers have shown that additive manufacturing (AM) may provide significant benefits in the current manufacturing sector, and it is feasible that AM will be used across the board in the near future.

Many institutes and companies, including Airbus, Autodesk, HP, and Stratasys, are actively working on this technology's research and development. The most well-known of these companies is Airbus. According to analysts, the fields of computers, research, and engineering will all face blockages in the near future as a result of 4D printing, which is expected to reach a productivity plateau within 10 years (Gartner 2018). Because parts may be made from a variety of materials, metal additive manufacturing can provide unrivalled levels of creative versatility (Salmi et al. 2012; Strong et al. 2017). In 2018, the metal AM increased by 41.9 percent to $260.2 million from $183.4 million the previous year, a 41.9 percent increase. Furthermore, by the end of the forecast period (2018–2023), the global additive manufacturing and materials market is estimated to reach $35.10 billion, showing a compound yearly growth rate (CAGR) of 26.86 percent (Wohlers 2019). By 2030, the global additive manufacturing market for automobile and other vehicle parts and accessories, as well as other consumer products, will have progressed from prototype to mass production (Lu et al. 2015).

By enabling new business models, manufacturing flexibility, decentralised production facilities, and lower transportation costs, additive manufacturing will reshape the traditional supply chain (Ford and Despeisse 2016; Holmström et al. 2010; Khajavi et al. 2014; Rayna and Striukova 2016; Rayna and Striukova 2016). As a result of boosting the efficiency of the additive manufacturing process, lowering raw material costs, eliminating numerous manufacturing steps, and maximising material use, the value chain will be totally reconfigured. Additive manufacturing will improve the supply chain as technology advances by cutting tooling costs and enabling faster changeover times. The purpose of developing an AM implementation plan is to reduce costs and increase the value of goods and services while retaining or improving competitive advantage over the competition.

Additive manufacturing has the potential to become a mainstream production technique and a crucial component of every manufacturing manager's toolkit as its application in a range of industrial sectors expands in the not-too-distant future. Despite its obvious benefits, this technology has struggled to obtain widespread acceptance in the worldwide manufacturing industry. Several academics underlined the need of incorporating additive manufacturing into their organisations' operations in their talks (Despeisse et al. 2017; Ivanov et al. 2019; Ryan et al. 2017). Only a few industries are covered, including aviation, automotive, medical, and consumer goods.

A key stumbling barrier in the adoption of additive manufacturing is determining the best appropriate additive manufacturing process for certain industrial applications. The need to upgrade existing capabilities or build new infrastructure is a significant roadblock to the widespread adoption of AM across a variety of industries. A number of studies have looked into the factors that drive AM implementation, including as organisational, technological, strategic, operational, and supply chain-related factors, as well as AM implementation characteristics in general. Mellor et al. (2014) looked into how additive manufacturing (AM) can be used in the engineering services industry. Several scholars, including Deradjat and Minshall (2017), have recently highlighted the importance of key AM implementation components in the dental industry. In a similar vein, Dwivedi et al. (2017) looked into the challenges of applying additive manufacturing technology in the Indian automotive industry. This finding demonstrates that researchers put in a lot of effort to look into the factors that influence AM uptake. However, because the vast majority of studies focus on a single instance or setting, extrapolating or generalising the findings from these studies is very impossible.

Although the operations manager does not need to be an expert in every aspect of AM implementation, he or she should be conversant with the various components. The majority of manufacturing organisations are unable to appreciate key features of additive manufacturing technology adoption. It's the result of a lot of research and thought that went into it beforehand. At, we see additive manufacturing as a viable alternative to traditional manufacturing methods.

2.2 Theoretical Foundation

2.2.1 The main processes

The core concept behind additive manufacturing is that three-dimensional objects are generated by combining materials in layers. A computer saves data, processes geometric information, and provides advice to the user in all additive manufacturing systems, as well as a deposition material that is treated by points, lines, or regions to produce parts (Bourell D et al., 2018). According to the ISO/ASTM 52900 standard, "the process of mixing materials to produce items from 3D model data, usually layer by layer, as opposed to subtractive and formative manufacturing processes" (ISO/ASTM, 2015). According to the definition of additive manufacturing, it is "the process of mixing materials to produce objects from 3D model data, usually layer by layer, as opposed to subtractive and formative manufacturing approaches." It is possible to build complicated geometric items with minimum post processing and nearly no waste using additive manufacturing techniques (Bikas & Stavropoulos, 2016). The ISO/ASTM 52900 standard defines seven process categories: binder jetting, directed energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination, and vat polymerization (ISO/ASTM, 2015). Binder jetting is one of the seven process types. AM technology can be classified using a variety of methods. One common approach is to categorise operations based on their baseline technology, such as whether they are performed with lasers, printers, extrusion technologies, or other similar devices and technologies. Another option is to organise processes using process groups based on the type of raw material input. The problem with these classification methods is that some processes (such as Selective Laser Sintering and 3D Printing) are grouped together in strange combinations, while others that appear to produce similar results (such as stereo-lithography and material jetting (MJT) with photopolymers) are separated. As a result, utilising a single classification system is probably not a good idea in this situation.

This two-dimensional categorization strategy was utilised in the early phases of classification (Wohlers 2019). The first dimension has to do with how the layers are arranged in the final product. Previously, the image was formed by drawing a single point source across the surface of the base material. As throughput rose, later systems increased the number of sources, which was made possible by "droplet deposition technology", which may be integrated into a one-dimensional array of deposition heads, for example. Additional throughput gains can be achieved by combining 2D array technology, such as digital micro mirror devices, with high-resolution display technology, which can reveal an entire surface in a single pass. Using this classification alone, on the other hand, leads to the aforementioned anomalies, in which a wide range of processes are grouped together (Lu et al. 2015).

By adding a second raw material dimension to the categorisation, the problem can be solved. Pham employs four different material classes, each with its own set of characteristics. Liquid polymer, discrete particles, molten material, and laminated sheets are the four different material categories used by Pham. Despite the fact that some of the more odd systems addressed in this book do not cleanly fit into this category, they are nonetheless worth discussing (Salmi et al. 2012). A theoretically conceivable deposition of a composite material, such as concrete, using an extrusion-based process is one example. It works well as a one-dimensional channel, but the substance isn't specified because it isn't molten to begin with. Future technologies could be developed that use 3D holography to project and construct entire things in a single pass. There may be processes or systems that do not fit into any of the categories, as there are with many other things. As long as proper mechanisms are in place to allow for the growth of this classification, there should be no issues.

Vector and raster-based scanning technologies are used in 1D and 2D channel systems to create a more comprehensive scanning solution. The outline is typically traced first, then the layer is filled in with regular or irregular scanning patterns (Huang et al. 2013). The outline is usually referred to as a vector scanned pattern, while the fill pattern is referred to as a raster pattern. Producing vector scanned patterns has a higher cost. Array approaches are rarely used to distinguish between the outline and the fill (Kinghels, 2015). Although one of the first and now-obsolete methods, “Cubital's Solid Ground Curing”, used liquid photopolymers to create a 2D channel method, most additive manufacturing procedures started with a 1D channel method (though this is debatable).

To keep up with technological advancements, more of the categorization array's boxes were filled in. If researchers and engineers use the empty boxes in this array as a guide for future technical breakthroughs, they may be able to make significant progress. In the majority of one-dimensional array approaches, at least two one-dimensional lines are used. Traditional two-dimensional printing, in which each line deposits a different material in a different position inside a layer, is akin to three-dimensional printing (Wohlers 2019). The Connex method, which use Stratasys' PolyJet technology, is an excellent example of this, as it allows you to create goods with a variety of material qualities in a single step. A sequence of 1D arrays, each holding ink or a different coloured material, can be used to print colour 3D things. The sheet laminating Mcor technology is referred to as a 1D channel approach since the component colouring is removed from the layer manufacturing process.

Manufacturers' systems are fast evolving to include, among other things, flexibility to deal with dynamic changes, high intelligence to enable autonomy, and sustainability to benefit the environment (Salmi et al. 2012). Many new and inventive production processes have evolved in recent decades, but pinpointing a single, stand-alone manufacturing method that can deliver the level of flexibility required has proven difficult. Hybrid Manufacturing is a technique for creating items with higher quality and shorter lead times by combining the advantages of two or more processes in a single workstation (HM). In HM, the relative advantages of each approach can be combined to produce geometrical accuracy and mechanical properties that are both dependable. When you work with a material, measure it, and then work with it again, you get a higher-quality component with fewer flaws. While HM is concerned with the overall process, it is less so with the specifics of each stage.

A hybrid process assumes that the sum of the individual processes provides a result that is greater than the sum of the individual processes. Hybrid processes are also defined as those that control the simultaneous interaction of several mechanisms and activities in order to get a more effective output. Machinery, materials, and processes are three of the most important categories into which HM technologies can be grouped (Huang et al. 2013).

2.2.2 Types of materials used

As the material used to create a printed product has an impact on the shape, dimensions, durability, and cost of the product, the variety of applications for which it can be utilised is significantly reduced as a result. The future generation of 3D printers will require improved processing methods in order to be capable of producing a wider range of materials than those already available, despite the fact that additive manufacturing currently only offers a limited amount and diversity of materials. Liquids, solids, and powders are the three categories of materials that are most frequently encountered in the work environment. Ceramics, composites, metals, and polymers are only a few examples of the materials present in each of these three groups, and there are many more (Noorani, 2018). (Noorani, 2018). In additive manufacturing, the materials used should be selected in accordance with the additive manufacturing method being used (Noorani, 2018; Chua et. al., 2017). According to Bourell and colleagues (2015), a relationship between the most regularly used materials for each of the seven categories of the ISO/ASTM 52900 (2015) standard was established (Bourell et. al., 2018).

2.2.3 Speed

High-speed CNC machining surpasses additive manufacturing equipment by a factor of several orders of magnitude when it comes to material removal. Although additive manufacturing (AM) can produce a part in a single step, this is only one aspect of the process. CNC machines necessitate extensive setup and process planning, especially as part geometries get more complex. As a result, rather than focusing solely on the physical contact between the part material and the machine, speed must be considered throughout the process. CNC is most frequently a multistage manufacturing process that requires part repositioning or relocation within a single machine, or the utilisation of many machines in one operation (Bourell et. al., 2018).

An item can be manufactured in a matter of hours on an additive manufacturing machine, and several elements are commonly merged into a single AM construct. It may be required to wait a few days in order to achieve truly high-quality outcomes. When dealing with high-complexity items, even 5-axis high-speed machining, it is possible that it will take weeks to complete, with the completion date being considerably more unpredictable. This is owing to the rigorous planning and production of specialised jigs and fixtures that are required to manufacture the part for the first time in order to achieve this result (Salmi et al. 2012). CNC machining, on the other hand, may be more efficient than additive manufacturing for the second and subsequent components.

2.2.4 Complexity

As previously indicated, additive manufacturing (AM) is more advantageous to CNC the more geometric complexity there is. Some geometric elements of a part may be impossible to create when utilising CNC to fabricate a part in a single piece. A spindle is required to convey a machining tool, which may create accessibility issues or clashes that prevent the tool from being placed on the cutting surface of the part (Salmi et al. 2012). Because additive manufacturing technologies are not constrained in the same manner as traditional manufacturing processes, they can be utilised to generate undercuts and interior features without a comprehensive process design. Certain parts can only be CNC made if they are disassembled and rebuilt into smaller components. A machining specialist must inspect an item before it can be created to guarantee that it can be constructed and to establish the techniques that will be utilised to manufacture it. While it is still possible that some parts cannot be manufactured via additive manufacturing, the chances of this happening are slim, and workarounds are usually simple to execute (Bourell et. al., 2018).

2.2.5 Accuracy

Because of the nature of additive manufacturing, the maximum resolution of AM machines is a few tens of microns, which is standard for this technology. AM machines are commonly used to produce parts with varying resolutions along various orthogonal axes, according to industry standards (Bourell et. al., 2018). The vertical build axis is widely used to define layer thickness on the building plane, despite the fact that its resolution is less precise than the other two axes on the building plane. The placement of the build mechanism, which will almost always contain gearboxes and motors of some sort, will dictate the precision of the build plane and vice versa.

To calculate the smallest possible feature size, this method could be employed. Using the example of stereo-lithography, the manufacturing process comprises a laser, which is often positioned using galvanometric mirror drives to obtain the desired outcome. The overall size of the parts manufactured would be determined by the resolution of the galvanometers, while the minimum wall thickness of the parts manufactured would be determined by the diameter of the laser beam (Huang et al. 2013). Cutter-Head-Centered (CNC) machines, in contrast, have the same positional resolution and rotary cutting tool diameter along all three orthogonal axes of operation. Even though the radius of internal corners is defined by the tool geometry, the wall thickness may be less than the tool diameter in some situations due to the fact that it is a subtractive process in some cases. In all circumstances, the level of detail will be dictated by the expected shape of the structure as well as the characteristics of the construction material used (Salmi et al. 2012).

2.2.6 Geometry

AM machines are capable of effectively breaking down a complex three-dimensional issue into simple two-dimensional sections with a predetermined thickness. This method causes the 3D link between surfaces to be severed, and continuity is determined by the distance between cross-sections between surfaces. Because it is difficult to do with a CNC, the majority of surface machining is done in three-dimensional space (Salmi et al. 2012). For simple geometries such as cylinders, cuboids, cones, and so on, this is a straightforward method that is represented by connecting points on a path, with the points being spaced far apart and the tool orientation being fixed. It is possible that these spots on freeform surfaces will appear relatively close together if there are frequent changes in orientation (Kinghels, 2015).

2.2.7 Programming

Numerous parameters, such as the choice of tool, the machine speed settings, the positioning of the approach and the angle of the approach, and other considerations, can have an impact on the programming sequence of a CNC machine. When known process parameter combinations are employed, the range, complexity, and consequences of the options offered by many additive manufacturing machines are minimised. This is true despite the fact that many additive manufacturing machines offer a wide range of possibilities. Most additive manufacturing machines have a low failure rate if programming and process parameter selections are done incorrectly. The worst that can happen is that the component will not be manufactured properly (Kinghels, 2015). A mistake in CNC machine programming can result in catastrophic damage to the machine and, in rare situations, even the loss of life of individuals who operate the machine.

2.2.8 The advantages and limitations of AM technology

As previously stated, one of the most significant advantages of additive manufacturing is that it allows for the construction of geometrically complicated products that were previously difficult to make with traditional methods without the use of a complex machine setup or final assembly (Boschetto et. al., 2015). Aside from that, it has previously showed adequate performance in the production of small batches (Yamazaki et. al., 2016). Additive manufacturing, according to Noorani, has the following advantages:

- After the parts have been consolidated, a complete set is formed.
- Additive manufacturing can be used to manufacture thin walls in various applications.
- They can be as lengthy as you want them to be, depending on your preferences.
- The machines are self-contained and require no external power.
- The more the sophistication of the part, the larger the cost savings.
- Automated pre-processing is available.

The capacity to manufacture parts in less time isn't the only advantage of being able to work more quickly. The usage of computers throughout the product development process can aid in the acceleration of the development process. The same could be said for 3D CAD and additive manufacturing: WYSIWYG in additive manufacturing is becoming WYSIWYG in manufacturing, and 3D CAD is becoming WYSIWYG in manufacturing (WYSIWYB).

Because of the reduction in the number of phases in the process, the operation's seamlessness may be displayed in the process (Bourell et. al., 2018). Building in an additive manufacturing machine is typically accomplished in a single phase, regardless of the complexity of the things to be manufactured. For the vast majority of alternative production processes, iterative stages would be required on a number of occasions. As additional aspects are included in a design, the number of phases in the design process may increase significantly. In contrast, minor design alterations have little impact on the time it takes to manufacture models using additive manufacturing techniques at this early stage of the product development process.

In a same vein, AM can drastically reduce the number of procedures and resources that are necessary. It is possible that a competent craftsman will discover that the part needs to be created in stages after being asked to construct a prototype from CAD drawings. Prototypes are created using computer-aided design (CAD) designs. Having to use a variety of construction processes, from hand carving to moulding and shaping procedures to CNC machining, could be an irritant for him given his lack of experience with them. Hand carving, which is prone to errors, requires a significant amount of time and is difficult to complete. It is necessary to build one or more moulds in order to mould a finished object, which is a time-consuming and messy operation (Yamazaki et. al., 2016). CNC machining, which may entail the fabrication of fixtures prior to the manufacture of the component itself, demands a meticulous planning method as well as a sequential production technique to be successful. The assumption here is, of course, that these technologies are already part of a craftsman's toolset and are readily available to him or her.

Many of these multistage processes can be avoided or simplified by using additive manufacturing techniques. Through the use of a variety of supporting technologies, such as silicone–rubber moulding, together with additional equipment and machinery such as drills, polishers, and grinders, among other things, it is possible to make a diverse range of parts with varying levels of quality. Workshops that are facilitated using AM technology have the potential to be considerably cleaner, simpler, and more adaptable than traditional workshops.

However, additive manufacturing still has a number of limitations, and it is not yet considered to be a totally viable technique of production. For example, it needs a considerable financial investment up front, it has not yet demonstrated performance comparable to other traditional methods, and the parts produced are not highly precise. It is necessary to meet surface finish standards when comparing additive manufacturing goods to traditional manufacturing techniques such as machining, and these requirements are fairly stringent. Due to the rapid cooling of the material, which creates distortions and strains in areas of the piece that are cyclically loaded or heavily stressed, these constraints are imposed by thermal and mechanical considerations. The orientation of the pieces, the thickness of the layers, and the direction of material deposition are all important factors that influence surface quality (Boschetto et. al., 2015). Additive manufacturing has been used successfully in the field of biomedicine to create bespoke implants for patients who require them. On the other hand, nearly all commercial operations that make use of this sort of production are constrained by the availability of raw materials for processing. It is also necessary to perform further treatments, particularly in the case of biological applications, in order to optimise the surface characteristics.

According to Tofail and colleagues, the technologies of "materials" and "metrology" are crucial enablers for the additive manufacturing process. They urge that additively generated things address the challenges that develop as a result of their manufacturing in order for them to function correctly. They accomplish this by putting out the scientific and technological hurdles that the goods' manufacture, materials, and metrology will confront in the future, all of which will have an impact on their market acceptance and economic feasibility in the present. As an example, when it comes to geometric deviations, concerns with tolerance management can be highlighted as a barrier to the development of predictive models and realistic simulations, among other things.

2.3 Empirical Research

To provide a general overview of critical additive manufacturing research and development activities, a variety of novel research subjects and approaches have been chosen and addressed. For the last few years, researchers have been developing hybrid machines that combine additive manufacturing with traditional procedures such as machining. Hybrid manufacturing combines additive and subtractive manufacturing techniques to produce a near-net shape that is then precision machined to its final shape (Zhu et. al, 2013). As a result, the issue of surface smoothness and precision in additive manufacturing has been resolved, and the capabilities of subtractive manufacturing to accommodate more complicated shapes have been expanded.

Adopting additive manufacturing methods and technology is a hassle and a significant financial investment for the majority of traditional firms. Strong and colleagues are examining the feasibility of establishing a network of strategically located additive manufacturing centres that would combine hybrid additive manufacturing with the capabilities and excess capacity of a number of traditional manufacturing plants. To meet the growing demand for advanced metal parts, it may be possible to build additive manufacturing capabilities that are more tightly coupled to current traditional manufacturing supply networks. Elser and colleagues propose a strategy for combining additive and subtractive manufacturing methods in order to maximise their individual and collective benefits. A hybrid computer-aided manufacturing system is created when a subtractive computer-aided manufacturing (CAM) system is linked to modules that enable the creation of additional additive manufacturing phases, resulting in reduced planning requirements. The aforementioned issues are addressed in this research via information flows and processes, which presents a framework for computer-aided hybrid manufacturing.

Multi-material systems are now possible with 3D printers, whereas they were previously unthinkable. These approaches enable the creation of pieces that make use of the unique qualities of a variety of materials. Despite the fact that this technology is still in its infancy, the authors examined the applications of various materials and considered the advantages and disadvantages. Bandyopadhyay and Heer examined the applications of various materials, as well as their advantages and disadvantages. Combining additive manufacturing and biomaterials looks to be a feasible method of enhancing human health and quality of life. Bose et al. thoroughly review a variety of additive manufacturing materials before discussing their application in a variety of therapeutic situations.

BAMOS (Biomaterials and Additive Manufacturing: Osteochondral Scaffold) is a multimodal treatment for osteoarthritis. One of the project's goals is to develop new biomaterials that enhance bone and cartilage development in the body's tissues. Additionally, novel additive manufacturing techniques for the fabrication of patient-tailored osteochondral scaffolds are being researched (Monzón, 2018). Bio printing is a topic of discussion in today's scientific community. Current research efforts are directed toward developing cutting-edge biomedical solutions. Campos et al. provide an excellent illustration of this. The authors propose merging micro extrusion printing and drop-on-demand (DOD) bio printing to create a synchronised dual bio printing approach for cartilage tissue generation. Recently, innovative materials with amazing mechanical capabilities were discovered, and this is one of the most interesting uses of this emerging technology. Zadpoor provided a comprehensive analysis of additive manufacturing metallic meta-biomaterials for bone substitutes and orthopaedic implants in the journal Advanced Materials. Li and colleagues compiled a list of recent advances in a range of additive manufacturing materials.

Because the bulk of the characteristics must have a length more than 0.5 mm.

According to Bhushan and Caspers, inkjet and SLA methods are well-suited for micro-additive manufacturing since they create smaller outputs than standard additive manufacturing. The samples were manufactured on a micro scale, with the SLA printed samples having a thickness of approximately 200 microns. Additionally, when printed with an inkjet printer, the samples were approximately 340 m thick (ProJet 3510SD).

Shaw et al. investigate micro extrusion in additive manufacturing using their own developed high-aspect-ratio (HAR) nozzles. Extrusion parameters such as nozzle moving speed, piston speed, extrusion rate, distance between the nozzle and the substrate, extrusion delay in response to ram speed change, and trapped air pockets inside the material reservoir were found to affect the quality of the deposited plane. Extrusion delay in response to changes in ram speed, nozzle moving speed, piston speed, extrusion rate, distance between nozzle and substrate, and trapped air pockets inside the material reservoir were all included.

According to several scholars, quality assurance and control are the most difficult challenges associated with additive manufacturing products. This issue must be addressed through the implementation of inspection and monitoring systems in order to improve the quality of objects and additive manufacturing processes. Chua et al. discovered that the size and temperature profile of the fusion assembly are significant hurdles to monitoring and inspection operations after examining current methods for regulating and monitoring additive manufacturing processes. Additionally, this organisation offers a quality control inspection method and a closed-circuit monitoring system for metal additive manufacturing operations.

Numerous process parameters have an effect on the quality of additively made products. Numerous studies have been conducted to determine the effect of various variables on surface roughness. Numerous research have been conducted to examine these qualities as well as a variety of post-processing techniques in try to improve the finish (Kantaros et. al., 2013). To meet output requirements, process parameters are optimised to produce the desired surfaces, with numerous combinations of the piece orientation, construction orientation, and layer thickness being generated in the initial stage in the standard triangle language (STL) file (Kumbhar, et. al., 2016). The process settings are optimised to generate the proper surfaces for the output needs, with many permutations of piece orientation, construction orientation, and layer thickness generated in the initial stage in the standard triangle language (STL) file. Pérez et al., for example, examine the effect of different printing parameters on the surface roughness of PLA samples generated using FDM. They concluded that, in addition to layer height being the most important factor in roughness, the thickness of the wall has a significant effect on the surface roughness results, as other studies have revealed.

The many by-products of the procedure are also being investigated. Alafaghani and Qattawi, for instance, do research on the surface quality and mechanical properties of FDM samples (tensile strength testing). According to the study's authors, a single configuration cannot optimise both outputs simultaneously. They compared the mechanical parameters of 3D-printed PLA to those of homogenous injection-moulded PLA and determined that 3D printing produces PLA with greater toughness than injection-moulded PLA. Numerous processing approaches, such as the one published by Zhu et al., are also available for investigation and review. To model shape deviations, the authors propose combining a prescriptive deviation modelling method with machine learning methodologies. In yet another study, Umaras et al. provide their findings from an assessment of the key processes of additive manufacturing as they relate to dimensional changes during part development.

Due to the layer-by-layer approach used in 3D printing, the mechanical properties of 3D printed items vary depending on the direction in which they are generated. Carbon's ground-breaking Digital Light Synthesis technology combines digital light projection, oxygen permeable optics, and programmable liquid resins to create solid interior components with consistent and predictable mechanical properties that are identical to injection-moulded components (Digital Light Synthesis, 2021). Ultrasonic additive manufacturing (UAM) is a form of metal 3D printing in which metal sheets are vibrated together. This method, according to Hehr et al., can be utilised to incorporate a curved component made of neutron-absorbing materials. This strategy is expected to save money by expediting the fabrication of control elements for Oak Ridge National Laboratory's High Flow Isotope Reactor (HFIR) (ORNL).

According to Zawada and colleagues, multi-layer cryolithography is being investigated as a new way for combining water-based chemicals. This technique includes printing many independent 2D layers in parallel on surfaces coated with hydrophilic materials. Individual layers are stacked on top of one another to form a three-dimensional structure that is then frozen following crosslinking with a chemical solution. One of the applications is the ability to build a live organism. Tissue engineering and food engineering are two of them. Dilip and colleagues put solid state material to a surface via a process called "friction deposition." The ASTM A240-compliant stainless steel cylinder passed microstructural and friction tests, demonstrating additive manufacturing's potential. Data collection is critical in reverse engineering, but it is even more critical in biological applications. The data is scanned using computed tomography (CT) and magnetic resonance imaging (MRI), and is then converted to printable CAD/STL files (Manmadhachary, 2019). Manmadhachary delivers a research article on the additive creation of an adult human dry mandible utilising 3D CAD models and optimised CT scan data using Taguchi and Gray relational analysis methods. The dry mandible can be created using FDM after the best CT scans are acquired. After collecting the highest-quality CT scans, the dry mandible can be printed using a scaled STL model. Xiao and colleagues demonstrate an automated and precise soft tissue face prosthetic additive printing technology using 3D colour image reproduction. When compared to traditional manufacturing processes, 3D printing was found to be capable of producing exact skin colours, delicate textures, and three-dimensional shapes while saving time and money.

Sustainability is one of the hottest topics in the manufacturing business right now. Environmentally friendly manufacturing practises are being promoted by governments, professionals, and businesses alike. Additionally, it is being pushed to ensure that the new additive manufacturing techniques are environmentally friendly or have a negligible influence on the environment. Economic reasons are currently driving the adoption of additive manufacturing technologies, with social and environmental issues coming in second or third (Niaki et al., 2019; Kumar & Czekanski, 2018). Kumar and Czekanski investigated two additive manufacturing technologies, SLS and FDM, both of which rely heavily on polymers. According to the authors, any polymers that are not used in the production of SLS powders (and would otherwise be discarded) should be repurposed as feedstock for low-cost, high-value FDM products. This would result in significant energy savings while also having a positive influence on the environment.

Additionally, the utilisation of recyclable materials is being examined more rigorously. Fateri et al. investigate a solvent-cast direct-write technology in this field, utilising biodegradable polyvinyl alcohol (PVA). The viscosity of the solution, the rate of evaporation, the print pressure, and the scan speed were all investigated and analysed in this study. As a result of their examination, the scientists discovered that the technology may be used to create complex structures with suitable mechanical qualities. Additionally, they discussed the physical and chemical qualities of the spacecraft's components.

Product qualification and certification (QC) are critical processes that must be conducted throughout the product's creation and marketing to guarantee that it has passed performance and quality assurance testing and complies with all applicable standards, specifications, and contracts. Quality control is often critical in industries where a product failure could have serious ramifications for the health and welfare of its users, such as the pharmaceutical industry. As a result, industries such as aerospace and medical devices rely on established standards for not only evaluating materials, components, and devices, but also for evaluating the design of tools and equipment to ensure quality and workmanship; inspecting and assessing instruments to ensure quality and workmanship; and developing procedures for operations, maintenance manuals, and regulations.

The four steps of the quality control process are application, evaluation, decision, and surveillance or recertification (Wohlers 2019). In most cases, independent agency or laboratory testing is followed by an examination by a product certifier to ensure that the test results accurately reflect compliance with the qualifying standards. It is usual practise to certify goods manufactured using ancient ways by adhering to established criteria and processes for antique materials and production methods. The data collected can then be compared to previously established data ranges and criteria to ensure that products meet the needs of the manufacturer, the end user, and other stakeholders.

As a result of these assessments, it is clear that component dependability and performance repeatability are critical for effective quality control (Yamazaki et. al., 2016). As a result of these issues, quality control (QC) of additively manufactured items can be challenging, and the path to effective QC can be complicated. On the other hand, the path to quality control for conventionally manufactured products is well-known and understood; it was enabled in part by vast amounts of historical data and research on material properties and manufacturing processes, which formed the basis for industry-accepted measurement standards.

In addition to current standards, having such well-resourced databases and information repositories simplifies and transparentifies the certification process. Standards produced by the American Society of Testing and Materials (ASTM) are crucial in facilitating the quality control of parts manufactured for the aerospace industry since they enable the evaluation of materials, components, and devices for the aerospace and aircraft sectors. To comply with FAA requirements, end products must pass three certifications: a Type Certificate indicating approval of the design, a Production Certificate demonstrating the installation of a sound quality control system, and an Airworthiness Certificate indicating the product is safe to use (Wohlers 2019).

The Type Certificate for a material validates that it has been empirically demonstrated to be durable and capable of keeping design characteristics. Rather than subjecting well-known materials to thorough testing, it is fair to rely on recognised reference materials (standards) to guarantee material qualities. Equivalency sampling is frequently required to guarantee that database performance can be replicated for composite or non-traditional materials for which standards are scarce or non-existent. Depending on the complexity of the device, obtaining sufficient data to statistically validate claimed mechanical properties may require between 5,000 and 100,000 test samples (Salmi et al. 2012).

Once the item is manufactured following receipt of the Type Certificate, it is critical to guarantee that it is manufactured using a quality control system capable of ensuring the repeatability of the Type Certificate design attributes. The production process is complete after a Production Certificate is obtained, and any alterations must be approved by the Federal Aviation Administration. Once the final stage is completed, the part or product is granted an Airworthiness Certificate certifying that it is safe to use. It is valid for the specified period of time if the authorised design is followed and the item or product is kept in excellent operational and maintenance condition (Huang et al. 2013). According to prior claims, this process can cost up to $130 million and take 10–15 years to complete for conventionally manufactured parts composed of conventional materials.

Reliable processes and inspection techniques for confirming part reproducibility and assuring repeatable process performance are also necessary to achieve repeatable process performance. This includes techniques for ensuring product specifications and consistent part production quality throughout the process, as well as enabling part evaluation (particularly non-destructive evaluation) and developing closed-loop control systems that allow for in-situ modifications and certification feedback data, as well as quantifying process variability and performance. Among other things, quality control and additive manufacturing components and processes demand the addition of datasets and data collection capabilities (Kinghels, 2015).

This project will propose procedures for capturing manufacturing data and component history, as well as create a publicly accessible database of statistical data on material and other quality characteristics. It would be more challenging to build an ideal quality control system than to merely adjust existing quality control systems to meet typical manufacturing procedures. Wohlers is a well-known name in the construction industry (Wohlers, 2019). In fact, following to the aforementioned aerospace certification procedure for additively manufactured parts and materials would be difficult if the AM process did not offer such a diverse range of mechanical properties and part quality. Three major sources of variation in this process are the input material, the AM technique used, and the post processing of the as-built output. In metal additive manufacturing, wire-fed, powder-fed, and powder bed feedstock materials can all be used, each with its own set of material attributes and monitoring criteria.

Additionally, the qualities of any given material (such as composition and shape) might vary significantly depending on the source. Plasma Deposition (plasma) vs. Laser Sintering (laser) vs. Electron Beam Melting (electron beam) vs. Plasma Deposition (plasma) vs. Plasma Deposition (plasma) vs. Plasma Deposition (plasma) vs. Plasma Deposition (plasma) (electron beam).

Indeed, the total number of input factors impacting the final output and hence demanding regulation to eliminate unpredictability may exceed 150 in a single AM approach. 2012 (Salmi and colleagues). Manufacturing the same item in many positions or orientations within the build chamber might occasionally result in a variation in the end product's quality. Postbuild variability is caused by variations in the processing steps necessary to rectify faults in dimensional tolerance, the presence of defects, the surface roughness of the product, and residual stresses.

Surface treatments to improve fatigue or corrosion resistance, precision machining to maintain geometric tolerances, and thermochemical treatments to reduce porosity or remove residual stress are all examples of operations that can affect the mechanical performance of the produced product. When all of these factors are considered, along with the fact that the AM process can be used with a wide variety of materials (metals, polymers, ceramics, and recently developed biomaterials), it is clear that the problem of unpredictability and the requirement for reliable control are significantly exacerbated (Bourell et. al., 2018).

Due to the diversity of additive manufacturing equipment and end users, there are no standard quality control standards and a number of roadblocks. Due to the limitations of current feedback sensors and data collection methods, it is not possible to provide real-time and closed-loop control. Due to a lack of standards, protocols, and norms, round-robin testing of materials and components is impractical, and the absence of data in standard formats and accessible via open, web-based third-party databases renders any attempt at certification nearly difficult. Numerous difficulties affect the entire range of additive manufacturing, from materials and modelling to design and manufacturing procedures (Bourell et. al., 2018).

2.4 Conceptual Framework

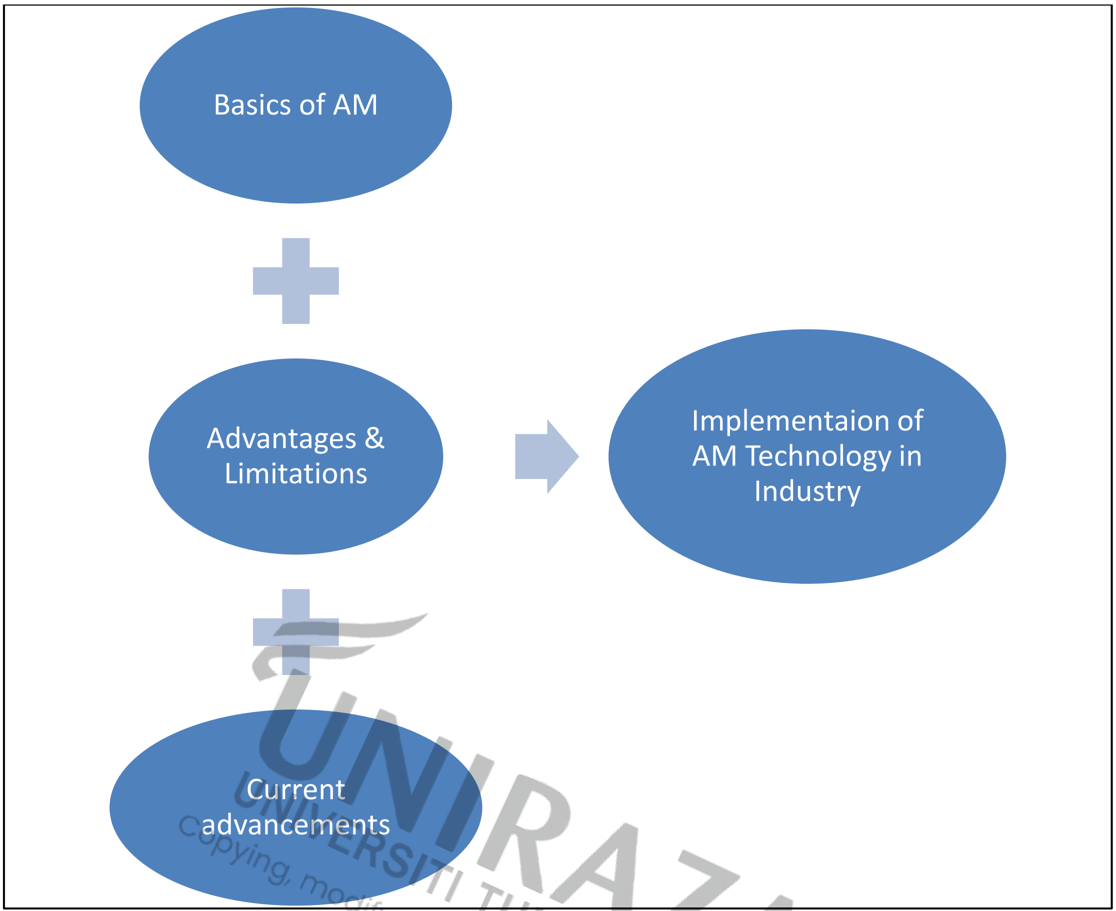

Figure 2.1: Conceptual framework

2.5 Hypothesis Development

1. The identification of implementation of AM in terms of factors to ensure the strategic requirements of firms are met greatly influences the performance of a firm in a positive manner.

2. Corporate leaders can achieve firm competitiveness by putting into practice various approaches based on AM basics and looking into the current advancements of this technology.

3. AM enhances the production and competitiveness of a company in long-term at international levels.

2.6 Chapter 2 Summary

In Chapter 2, the principles of additive manufacturing, the advantages of implementing this technology in the workplace, as well as the drawbacks and limitations of doing so. It also talks through the conceptual framework and hypotheses that were developed for the investigation.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

Eighteen problems have been identified based on the literature on AM implementation concerns that has been compiled. A total of five groups have been developed in order to bring together variables that are related to technology, organisation, operations, supply chain, and market dynamics in a cohesive manner. Studies such as those conducted by Deradjat and Minshall (2017) and Mellor (2017) have made use of the element of grouping off to improve their results. The AM implementation features are validated by the usage of industry viewpoints. This section goes into great detail on the methodology that was taken during the validation process.

3.2 Research Design

Case studies will be used as the major mode of analysis because AM research is still in its early stages. Sample selection, instrument construction, data collection, data tabulation, and data analysis are only a few of the processes involved in case study research.

3.3 Study Population and Sampling Procedure

The creation of theory from case studies needs the careful selection of cases (Eisenhardt 1989). There is currently no context-specific study in AM research that examines essential AM implementation elements and their influence on firm competitiveness, nor is there a study in other disciplines of research that examines essential AM implementation elements and their impact on company competitiveness. One of the goals of this study is to learn more about the elements that make AM deployment feasible. The example should address challenges associated to AM implementation in order to contribute to the advancement of theory. The findings suggest that the organisations in our sample are either already utilising ABM, are in the process of adopting it, or plan to utilise it in the future (Application Management).

The investigation will begin by developing a complete list of various companies, which will include a mix of OEMs, service providers, and component manufacturers. We sought for information regarding their AM technology installation and applications on their websites when looking for AM technology installation and application businesses on the internet. Based on the information provided, the following criteria were used to limit down the pool of applications:

- The performance of the organisation as a whole.
- Certification by the International Organization for Standardization (ISO) is a second option (ISO).
- The application of sectors or domains to a problem.
- The company's overall size and scope.

Prior to the research, the list will be narrowed down to significant developments In order to participate in the study, companies must first submit interview consent forms via email. Companies who did not respond to enquiries should cite a lack of time as well as concerns about data security as reasons for their refusal to participate. On the basis of their availability, the potential companies will be shortlisted. For acquiring a complete understanding of the phenomena under investigation with the ultimate goal of generating a theory, this sample size will be set within the recommended range of 4 to 10 samples (Eisenhardt 1989; Voss et al. 2002). In the subsequent step, we selected professionals from these firms based on the following criteria:

- Candidates must have a minimum of five years of relevant experience.
- Hands-on expertise with additive manufacturing technologies that is relevant.
- Your field of work.

Professionals will be approached via e-mail and phone, according to the preferences of the companies, in order to solicit their participation in the study project. By doing so, it will be possible to obtain their approval to participate, and a conscious effort will be made to collect a theoretical sample of organisations participating in a variety of activities, which will be referred to as a theoretical sample in this document. There will be case studies of businesses that have made the shift from traditional manufacturing to additive manufacturing, as well as businesses that have made direct investments in the technology. Companies covered in this sample mostly provide prototypes and components to other firms across a wide range of industries, including aerospace and automotive, as well as electronics and biomedical, as well as educational institutions.

Fusion deposition modelling (FDM), selective laser sintering (SLS), three-dimensional printing (3DP), and digital light processing are the most prevalent additive manufacturing technologies utilised today (DLP). An extensive range of organisations' experiences with the application of augmented reality (AR) technology is represented in the sample data. As previously stated, a number of codes are employed in this study to ensure that the identities and anonymity of all participants are maintained and protected. "Former" companies were defined as those with more than five years of AM experience, whilst "recent" companies were defined as those with fewer than four years of experience.

Because of the experimental character of AM technology and the stated goal of evaluating crucial areas of AM adoption from the standpoint of operational performance, we selected only those organisations that could devote adequate time to AM implementation expertise. As industry experts for this study, we gathered top management professionals with a wealth of knowledge and expertise in their respective sectors to serve as our subject matter experts. They, in our opinion, are in a unique position to provide insight into their respective organisations' strategic AM adoption decisions. We received consent from four firms, including CMS, 3PM, NEC, and KOP. These are only a few of the companies who agreed to participate in our research. Rather than conducting interviews with senior management executives, we elected to conduct interviews with respondents at the next lower level, notably project managers. Our sample included these businesses in order to gather as much empirical information as possible about their operations.

3.4 Data Collection Method

Quantitative or qualitative data, or a combination of the two, may be used in case study research (Yin 1984). As a result, designing tools and methodologies before going into the field to gather data is an important step in case study research, especially qualitative research. Scheduled interviews, informal chats, and unstructured interaction are all popular ways for researchers to obtain information for case study research (Choudhari et al. 2013; Kulkarni et al. 2014). The development of instruments has made it possible to adopt a methodical strategy to gathering the necessary data. Before visiting all of the companies, it was required to create an instrument. Information was gathered in two stages. During phase one, participants are informed about the research's aim and given an overview of the study, as well as an explanation of their role as a subject matter expert. We've been given permission to take part in the interview and record all of the essential outcomes.

3.5 Operationalization and Measurement

In order to obtain information, semi-structured interviews with representatives from each of the nine participating companies in the study was conducted. Industrial specialists were briefed on the study's research objectives and information requirements before being sent out into the field to conduct the research. The primary purpose of these interviews was to gain a better understanding of the extent to which additive manufacturing (AM) is being used in enterprises in India, as well as the significant hurdles to the adoption of AM in the country. In the semi-structured interviews, we addressed each issue on the list in a free-flowing discussion format, and we did not cover the themes in any specific order or sequence. The nine participants who took part in the study were four upper-level executives from four different companies (BHA-FRT, KAL, CAD, REV, and GNDMTR) and four project leads from CMS, 3PM, NEC, and KOP. The survey was conducted by a third-party research agency.

In each of the one-and-a-half-hour interviews, the comments of the participants and their responses were digitally recorded and transcribed. The experts provided answers to questions about the effectiveness and performance of additive manufacturing adoption in the Indian manufacturing sector. They also provided internal and external business documents on infrastructure practises, such as strategy plans, training methods, project report examples, and case studies, to their clients and prospects. During informal contacts with all of the specialists, further information was gathered.

In a case study, it is vital to have precise recording and tabulation of the data collected from the participants. Separate papers with firm information, expert qualifications, and the date of the interview were used to compile and total the responses from the experts. Furthermore, all of the responses were digitally recorded and transcribed before being saved in a data sheet. Following the creation of a transcript of the digitally recorded comments, the author conducted follow-up conversations with each of the experts to verify the validity of their responses. Before the second round of semi-structured interviews, the experts were provided with the information gathered during the first round of semi-structured interviewing.

After conducting a second round of interviews, it was discovered that respondents had failed to mention information about processes during the initial round. Telephone conversations with each of the specialists lasted an average of thirteen minutes and were conducted with all of the professionals. The study revealed major inconsistencies in the perspectives of people who participated as a result of the diverse nature of the research sample, which we believe is the cause of these findings. Several dimensions or noteworthy terms have been identified as a result of the quotes contained in digital transcripts as well as transcripts. The researchers uncovered 51 dimensions from a large number of transcript quotes in a similar vein that were digitised. With the use of these dimensions, we attempted to establish a link between these characteristics and previously published AM implementation variables in the literature.

3.6 Data Analysis Techniques

Beginning by looking at eighteen AM implementation parameters derived from various AM-SC types of literature as a starting point (AMIF). Similarly, as detailed in the prior section, several variables associated with the adoption of additive manufacturing technology are gathered via semi-structured interviews with industry specialists. We attempted to map the dimensions to the most appropriate AM implementation elements for the situation at hand. We enlisted the help of the same industry experts to map the indicated dimensions into AMIF. They were extremely accommodating. For the goal of mapping individual measurements to AMIF criteria, a Google form is created and shared with nine industry experts.

Finally, the responses of all of the experts were gathered into a single document. After then, the individual's judgements are used to construct a link between all of the professional responses (Horenbeek and Pintelon 2014). In this type of situation, the consensus correlation strategy is the most successful method of analysis (Dwivedi et al. 2017; Kavilal et al. 2018). In order to avoid bias, each expert is given a leaflet that summarises the considerations. Expert opinions were formed after a thorough examination of all relevant variables. As a result, the inputs are discovered to be of practical utility. The experts, in their perspective, contributed by mapping those dimensions to the appropriate AMIFs. The first dimension, for example, is mapped to the AMIF with the greatest degree of agreement, according to the AMIF.

3.7 Chapter 3 Summary

In Chapter 3, the research design, sampling procedure, data collection method, operationalization and measurement, and data analysis techniques were discussed in detail.

CHAPTER 4

CASE STUDY RESULTS

4.1 Case Study 1 – "A Conceptual Framework on Implementing Additive Manufacturing Technology towards Firm Competitiveness"

4.1.1 Overview

The authors' goal in this case study by Sonar et al. in 2020 was to look into important AM implementation variables from the perspective of operational performance, which they did. Previous research was used to identify AM implementation elements, as well as semi-structured interviews with industry specialists to get industry perspectives on the subject. Nine Indian manufacturing sector experts initially selected and analysed eighteen AM implementation elements, which were then improved and refined again. From the transcripts, we identified a number of dimensions or important phrases and sought to correlate those qualities across the various AM implementation pieces. Four issues were discovered during the procedure that were unrelated to the AM implementation technique. This study is unique in that it identifies crucial AM implementation variables and develops a conceptual model based on the relationship between AM implementation elements and competitiveness, indicating a structured method for leveraging AM to gain a competitive edge.

4.1.2 Conceptual Framework

Product customization is possible with additive manufacturing (AM), but it necessitates considerable changes in product development cycles, operating operations, and supply chain practises. By allowing organisations to differentiate themselves from their competition, AM can help them attain new levels of competitiveness (Deradjat and Minshall 2017; Gibson 2017; Tuck et al. 2008). However, in order to build competitive AM implementation strategies, the operations manager must have a thorough understanding of the many aspects of AM implementation. Increasing and maintaining competitiveness on both domestic and foreign markets is a never-ending cyclical process. Manufacturing operations must be able to produce world-class products with great product quality, delivery, and process cost (production competence) to enable the long-term competitive viability of AM deployment (Vickery et al. 1993). The "amount to which a company's manufacturing performance contributes to the fulfilment of its strategic objectives" is defined as production competence (Vickery et al. 1993). Some of the scholars who have looked into the positive relationship between production competency and company competitiveness include Cleveland et al. (1989), Dangayach and Deshmukh (2006), Demeter (2003), and Voss et al. (2004). Business boundaries have moved well beyond their national borders as a result of globalisation, and indicators of international competitiveness have become more important. As a result, additive manufacturing has the potential to improve the capabilities of persons working in the manufacturing industry. Competence in additive manufacturing could help the company increase its production capacity and hence increase its competitiveness in the long run. The conceptual paradigm depicted in Figure 4.2 is used to conceptualize this proposition.

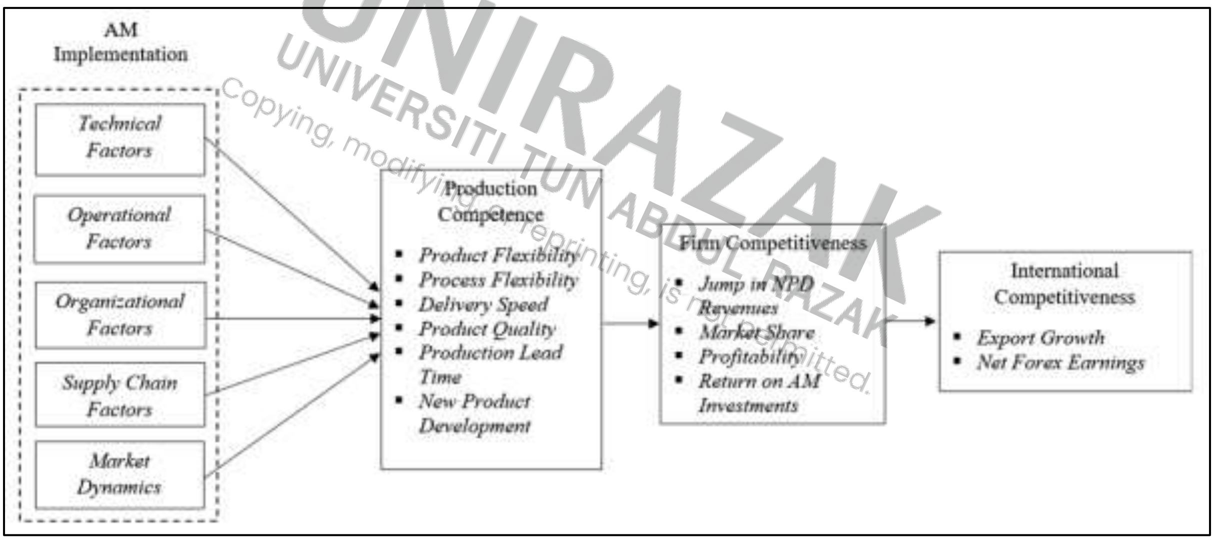

Figure 4.1: Connections between AM deployment and competitive conceptual model.

This conceptual model will require two investigations in order to be experimentally validated. Considering, among other things, manufacturing expertise, firm competitiveness, and global competitiveness Figure 4.2 shows the proposed measures for several conceptual conceptions. More study is needed to develop accurate competitiveness indicators. The relationship and links between AM implementation, production competency, and company competitiveness are derived based on past studies, and the ramifications are examined. Further empirical investigation is required to validate these links.

4.1.3 Data analysis

During the data analysis process, a more in-depth examination of the relationship between dimensions and AM implementation variables is carried out. This is accomplished by the use of a methodical procedure, as seen in Figure 4.1. We began by investigating eighteen AM implementation variables that were based on several AM-SC types that had been found in the literature (AMIF). Like the previous part, semi-structured interviews with industry experts are used to gather information about the many characteristics associated with the adoption of additive manufacturing technology. Attempts were made by the authors to match up the dimensions with the components of AM implementation that they were able to determine. When it came time to map the selected dimensions into AMIF, they turned to the same industry experts for assistance. They proved to be really beneficial. In order to achieve the goal of mapping individual measurements to AMIF criteria, a Google form is constructed and shared with nine specialists in the manufacturing business. The AMIF identification process is summarised in Figure 4.2.

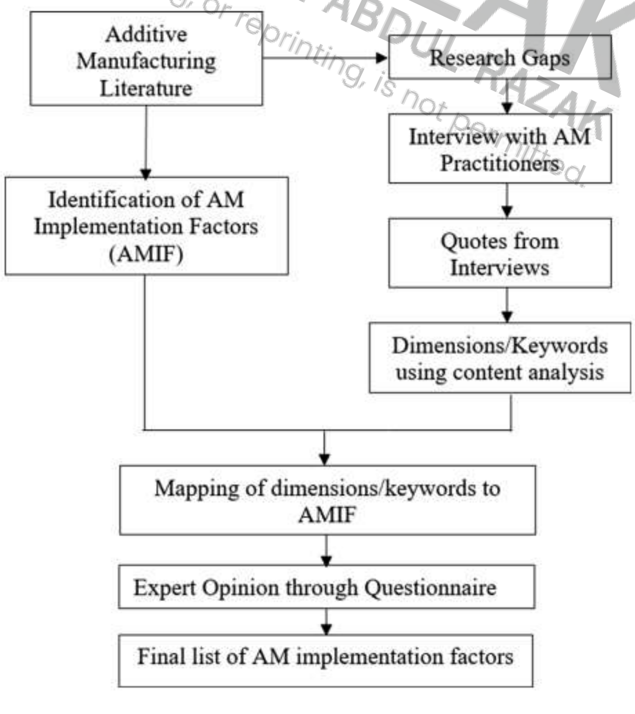

Figure 4.2: AMIF identification steps

Finally, all of the experts' responses were compiled into a single document. The individual's judgments are then used to create a correlation between all of the professional responses (Horenbeek and Pintelon 2014). The consensus strategy of correlation is the most successful method of analysis in this type of situation (Dwivedi et al. 2017; Kavilal et al. 2018). Every expert is provided with a leaflet that summarises the factors in order to eliminate bias. The opinions of the experts were formed after a careful examination of the relevant variables.

As a result, it is discovered that the inputs are of practical use. As shown in Table 4.1, the experts provided their recommendations by mapping the dimensions to the relevant AMIF. Table 4.1. In addition, the table displays the degree of agreement for each dimension in each dimension.

Table 4.1: Mapping sheet of factors

Dimensions/Keywords	*AMIF 01*	*AMIF 02*	*AMIF 03*	*AMIF 04*	*AMIF 05*	*AMIF 06*	*AMIF 07*	*AMIF 08*	*AMIF 09*	*AMIF 10*	*AMIF 11*	*AMIF 12*	*AMIF 13*	*AMIF 14*	*AMIF 15*	*AMIF 16*	*AMIF 17*	*AMIF 18*	*Degree of Consensus*
Product Cost	x																		9
Investment Cost																			9
Design for Additive Manufacturing																x	x		8
Part Complexity									x										8
Competitive Advantage																		x	9
Resistance to Change						x													7
Raw Material Supply				x															8
Design Security			x																9
Intellectual Property			x																6
Order Volume	x																		7
Material Properties	x																		9
Competitive Success																		x	8
Market Share																		x	6
Processing Speed & Cost	x																		9
Surface Finish	x																		9
Machine Overhead	x																		9
Customization														x					8
Customer Requirements											x								6
Supply Chain				x															8
Reliability	x																		7
AM Standardization													x						7
Workforce Experience & Skill						x													8
Quality Assurance						x													9
Time to Market		x																	6
Strategic Decisions		x																	7
Design Constraint	x																		8
Raw Material Cost	x																		9
Technology Benefits									x										8
Production Planning & Control Systems						x													8
Product Design & Data Management			x																6
Technology Trade-offs	x																		6
Machine Cost																			7
Process Lead Time	x															x			9
AM Process Planning													x						7
Organization Learning							x												7
Software Accuracy	x																		8
Size Constraints	x																		9
Product Innovations										x									8
Quality Control													x						7
Process Consistency													x						7
Technology Maturity	x																		8
Working Environment						x													9
Return on Investment																		x	8
Manufacturing Competence																	x		9
Skill Development							x												6
Personal Competencies							x												5
Core Competency						x													7
Value Proposition						x													6
Product Mix														x					9
Demand Uncertainty										x									7
Business Excellence																		x	9

For instance, the first component is mapped to AMIF number nine, which is the first AMIF with the highest degree of consensus. To put it another way, all nine experts examined the first dimension as part of the first AMIF, also known as the First Dimensional Assessment. But the authors observed that several dimensions are unrelated to the AM implementation process and have not been assigned to any important components, as previously thought. Only a few of the concerns that must be addressed are government support, opposition to change, organisational culture, and environmental uncertainty, to name a few. The result is the deletion of eight AMIFs, with the remaining fourteen AMIFs being deemed crucial for early AM adoption and as a result requiring mitigation as part of the AM implementation method. "

The investigation of AM implementation variables may result in the development of a systematic approach for utilising AM to gain a competitive edge in the future. Because of this, businesses will be compelled to rethink their business strategies in order to achieve a competitive advantage (Kulkarni et al. 2016). To determine a company's competitiveness, various criteria such as technology, new product development, quality, and a variety of other factors can be considered (Ambastha and Momaya 2004). Following the findings of the study sample, the most important factors influencing competitiveness were determined to be market share, return on investment, provability, and new product development, all of which are essential antecedents to total market performance. These factors were also determined to be the most important factors influencing competitiveness.

As a result, only these critical components of a company's competitiveness were taken into consideration during our analysis. The majority of the research was devoid of a substantial amount of empirical evidence supporting the efficiency of AM in enhancing company competitiveness, as demonstrated by the findings of the study. Many academics are becoming increasingly interested in themes such as how additive manufacturing technologies affect manufacturing, business strategy, and performance. Others are trying to figure out how to create a correlation between AM adoption and a company's competitiveness. Because of this, more research should be conducted with the goal of identifying critical AM implementation aspects and researching their impact on the competitiveness of small and medium-sized firms (SMEs).

4.1.4 Summary of case study 1

Adding value through additive manufacturing (AM), a process that was developed in the 1990s, is revolutionising manufacturing operations and their associated supply chains. Despite its obvious advantages, this technology has not yet gained widespread acceptance in the global manufacturing sector. In their presentations, several scholars emphasised the need of implementing additive manufacturing into the operations and processes of their respective companies. Although it is not necessary for the operations manager to be an expert in all parts of AM implementation, he or she should be familiar with the many components.

The vast majority of manufacturing companies are unable to comprehend critical aspects of the adoption of additive manufacturing technologies. The major purpose of this study is to leverage current data to identify essential AM implementation features from both a commercial and an academic standpoint, with the secondary goal of identifying critical AM implementation aspects. First, academic perspectives on AM implementation were used to define eighteen elements of AM implementation, which were determined as a result of a thorough review of relevant literature. An overall total of four groups has been established to bring together components from the technological, organisational, operational, supply chain, and market dynamics domains.

Through semi-structured interviews with nine industry experts from Indian manufacturing organisations, the validity of the AM implementation criteria that had been developed was then confirmed. It was necessary to use digital transcript quotations to extract the dimensions or vital terms from each conversation in order to properly transcribe them once they had been collected digitally. When it came time to translate the keywords into AM implementation elements, we sought advice from the same industry experts who had assisted us in identifying the keywords in the first place. During the investigation, we uncovered four criteria that were unnecessary to the AM implementation process, and as a result, they were removed from consideration.

Though no single perfect technique exists for determining key AM implementation variables, this research has provided important insight into generic AM implementation elements from an operational perspective, which has been validated by industry professionals. Also available is "conceptual framework" to assist factory managers in building AM implementation strategies that would give them a competitive advantage and enable their companies thrive in a dynamic global market. More research is required in order to develop a thorough technique based on the conceptual model that has been supplied. A larger number of organisations, as well as sector-specific research, could be investigated in order to improve the theoretical soundness of the proposed model. This research could be widened to investigate whether there is a relationship between AM implementation, from competitiveness, and performance on competitive priority tasks, among other things.

The investigation of AM implementation variables may result in the development of a systematic approach for utilising AM to gain a competitive edge in the future. The majority of the research was devoid of a substantial amount of empirical evidence supporting the efficiency of AM in enhancing company competitiveness, as demonstrated by the findings of the study. In the course of this endeavour, a conceptual model illustrating the relationship between the primary parts of AAM implementation and the competitiveness of a firm was developed. Future study, on the other hand, will need to put this conceptual paradigm to the test in an empirical setting. Aside from improved surface quality and product structure, other technical considerations that must be thoroughly investigated include Taguchi process parameter optimization, the response surface method, the Internet of Things integration of additive manufacturing, machining and input metal parameter, post-processing techniques, and AM energy consumption modelling. Additive manufacturing may be used to improve the innovative capabilities of companies in a variety of industries, including maintenance engineering, aerospace, medical, aerospace, jewellery, and the automobile industry, among others. The participation of the government and policy action in such key industries as additive manufacturing, for example, are critical to the manufacturing sector's ability to be self-sufficient.

4.2 Case Study 2 – "Additive manufacturing: A framework for implementation"

4.2.1 Overview

With the shift of mass production to developing nations, businesses in Europe and the United States are being forced to adapt fast to low-volume manufacturing of products that are more innovative, customised, and environmentally friendly, and that also have a high level of added value. Numerous fabrication techniques have been tested by manufacturers in order to give the essential tools for meeting growing demand for flexibility while also allowing for cost-effective low-volume manufacturing during this unpredictable period. The process of additive manufacturing is one of these cutting-edge technologies (AM). AM (additive manufacturing) is a manufacturing technology that builds products from digital 3D models by layer-by-layer mixing of materials. It is used in the production of medical devices. All of these benefits, as well as more design freedom and the elimination of the requirement for tooling, are provided by this technology. For many years, prototyping (also known as rapid prototyping) has been a well-known application of additive manufacturing, particularly in the automotive industry (AM). AM is a collection of technologies that can be used to process a wide variety of materials. AM is also known as additive manufacturing. Over the past few years, rapid manufacturing, also known as direct part production, has experienced a significant increase in popularity, driving intense research into novel techniques and materials. It was necessary to commission this study, which focuses on the implementation phase of AM, because there has been a dearth of socio-technical research in this area.

It emphasises on the need for existing and future AM project managers to have a framework to guide their efforts in adopting this new and potentially disruptive technology class in order to manufacture high-value goods and open up new business opportunities for themselves and their companies. After reviewing existing literature and doing qualitative case study analysis, we develop and analyse a normative structural model of implementation elements related to additive manufacturing technology (AM), supply chain management (SCM), organisation, operations, and strategy (Strategic Manufacturing).

4.2.2 Conceptual Framework

As shown in Figure 4.2, the conceptual framework for AM implementations proposed by the authors is illustrated. According to the framework, external pressures and internal strategy are the driving forces behind consideration of additive manufacturing as a manufacturing process, and the approach to AM implementation will be influenced by elements that may be grouped into five categories.

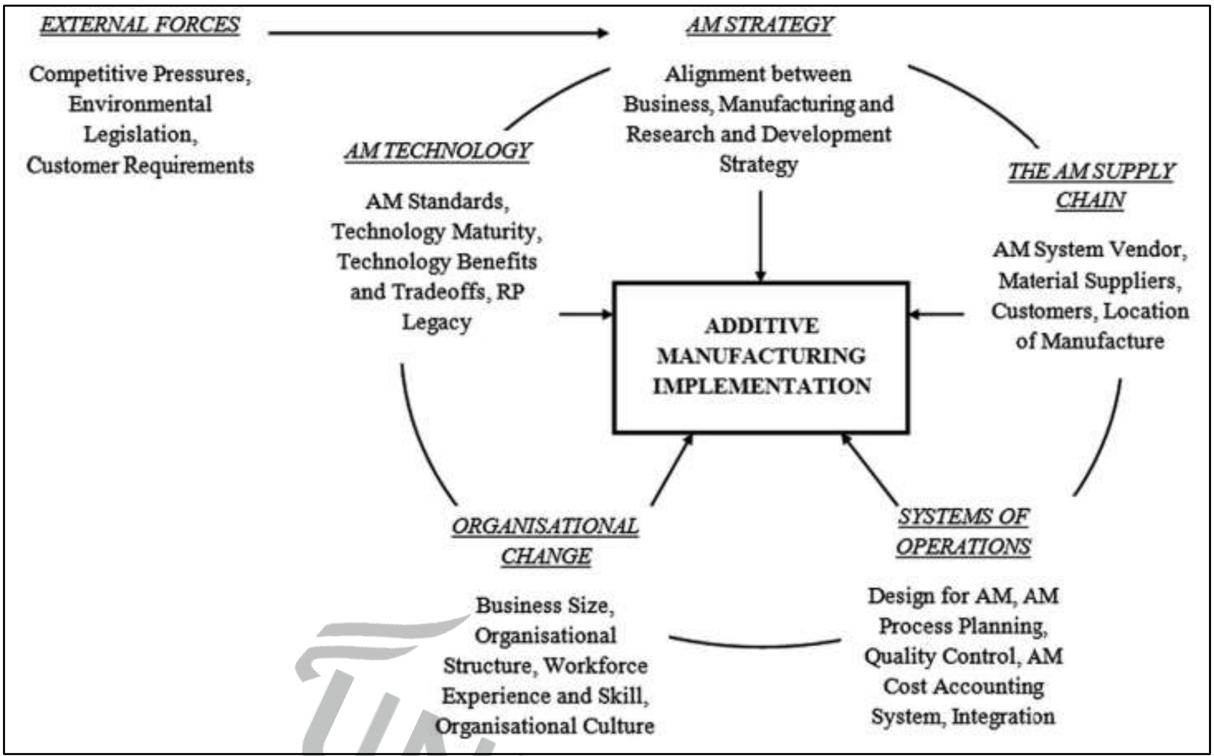

Figure 4.1: Proposed AM implementation framework

4.2.2.1 Strategic factors

It is critical to examine the market and product features before deciding whether or not to invest in Additive Manufacturing technology. If a technology isn't going to be substantially used on a particular product, it needs to be able to suit the manufacturing and business needs of other items as well (Hill, 2000)." A number of product characteristics have been presented by authors in the field of additive manufacturing management to determine the types of items that are suitable for additive manufacturing. The three most typical product features to find in a particular product are a high degree of customisation, greater utility through design optimization, and a limited number.

Prior to using additive manufacturing, business, manufacturing, and research and development initiatives must be strategically aligned. The technology's advantages must be linked to the manufacturing unit's capabilities, which may be found in the business strategy, which is considered as a market-pull approach to additive manufacturing adoption. In contrast, from the firm's existing resource-based perspective, investment in additive manufacturing (AM) could be viewed as a structural investment that will enable the company to develop new production capabilities, resulting in new commercial prospects, a technology-push approach.

4.2.2.2 Technological factors

One advantage that has been highlighted when it comes to AM adoption is the capacity to integrate technical benefits into the business plan. The technology benefits linked with AM technologies include a variety of other advantages in addition to the ones already listed. However, as proven in prior work by Sonntag, the adopting firm must be cognizant of the trade-offs involved with deploying new production technology (2003). In general, the material range for additive manufacturing techniques is limited, equipment and material prices are high, and process speeds are slow. Another significant impediment to wider adoption is the lack of technical standards. Because some of these characteristics are likely to be related with their relative immaturity, managers should be aware of this while considering whether or not to use AM.

The AM system also has an inherent RP background, which may present a psychological barrier to adoption because management only views the technology-class to be suited for RP applications. The success of the deployment will be determined by the adopting organization's ability to explain the benefits of additive manufacturing as a production method in a clear and balanced manner.

4.2.2.3 Organisational factors

According to study, a corporation's size is an important factor to consider while understanding the process of implementing new manufacturing technology. According to a number of academics, small businesses should not be viewed as scaled-down versions of larger businesses; theories that have succeeded in large corporations may not be appropriate for small businesses, according to the same academics (Federici, 2009; Schubert et al., 2007; Thong et al., 1996; Welsh and White, 1981). As a result, a small and medium-sized enterprise's (SME) implementation strategy is likely to differ from that of a giant global corporation. Dalton et al., 1980; Dean et al., 1992; Belassi and Fadlalla, 1998; Abdul Ghani et al., 2002; Sun and Tian Cui, 2007; Saberi et al., 2010) discovered that the structure of an organisation is the most essential component in successfully applying manufacturing technology (Saberi et al., 2010). As a result, in order to ensure a successful implementation, it is recommended that the decision to deploy AM technologies be followed by changes in roles and responsibilities, as well as changes in work practises and organisational structure.

Many authors argue that the usage of developing technologies is exerting pressure on established conventions and strategic options. The complex set of knowledge frameworks that members of an organisation use to perform tasks and develop social behaviour in the workplace is referred to as organisational culture, which is linked to structure (Saberi et al., 2010). The most significant yet unrecognised influence, according to "Hopkinson et al. (2006), may be on company culture and how it changes to support rapid manufacturing" (RM). Designers and engineers must rethink design for manufacture when using additive manufacturing techniques as a manufacturing technology (DFM). Design for Manufacturing (DFM) is a broad word that spans a range of subfields. It is defined as any component of the design process in which the challenges associated with creating the planned product are publicly investigated with the purpose of influencing the design. Users must match the product to the process and become familiar with new technology process capabilities in order to use AM. As a result, it is suggested that worker experience and competence be taken into account when implementing AM.

4.2.2.4 Operational factors

In accordance with Bailey (1993), a change in an organization's technological environment will result in changes to both the organization's operational and administrative structures. Many authors believe that the deployment of AM will have a significant impact on product design, which will change substantially as a result of its implementation. Researchers Hague and colleagues (2003) and Mansour and Hague (2005) have investigated the impact of additive manufacturing on product design and on designers, respectively. In addition, because additive manufacturing processes (AM) are additive processes by their very nature, they are not constrained by the limits of traditional manufacturing methods (subtractive or formative) (Hao et al., 2010). Because of the unique properties of additive manufacturing systems, the development of novel design tools and methods is required; contrary to early promises made by some researchers, there is not complete geometric freedom, and many factors must be considered when developing products for additive manufacturing processes. Understanding the additional design constraints associated with "additive" manufacturing is a critical component of the AM implementation approach, and designers' understanding of these constraints is essential.

Production planning and quality control are two more areas of operations that are predicted to undergo significant transformation as a result of the implementation of AM. The fact that Ciurana and Riba (Munguia et al., 2008) assessed the processing planning approaches employed at 36 Additive Manufacturing facilities in Northern Spain demonstrates that additive manufacturing process planning is still lacking in the literature. The approaches used in AM process planning were established through survey analysis and personal discussions with technicians, according to the authors. Strategies such as component orientation strategies, build volume strategies, layering strategies, support generation, and minimization were just a few of the approaches that were employed. In their discussion of this study's findings, they acknowledge, however, that RP and RT accounted for the vast majority of the activity, which they consider to be a limitation of their findings.

New technologies, according to the authors Hayes and Jaikumar (1991), result in a shift in the expenses incurred from direct labour to primarily fixed costs, rendering existing cost accounting techniques that focus on less significant parts unproductive. In their writings, some authors have pointed out that there is a substantial gap in knowledge regarding the genuine cost of an AM system, as well as the expenses associated with its installation and operation (Munguia et al., 2008; Grimm, 2004; Hopkinson and Dickens, 2003). In previous AM costing studies, four major cost elements for additive processes were found: operation times, equipment costs, labour costs, and material costs. These four cost elements were recognised as operation times, equipment costs, labour costs, and material costs. The four cost elements in this study were identified to be operation times, equipment expenses, labour costs, and material costs. An important study on the cost assessment of additive manufacturing technologies was published by Ruffo et al. (2006), and the study was later expanded to include the simultaneous creation of mixed components using laser sintering (Ruffo and Hague, 2007). Other systems, such as metal-based processes, on the other hand, continue to suffer from a significant knowledge gap.

In the context of additive manufacturing, post-processing (such as support removal, heat treatment, and so on) is necessary, and the integration of additive manufacturing inside a supporting production system is considered important to the implementation's success.

4.2.2.5 Supply chain factors

The adoption of additive manufacturing is at the crossroads of two supply chains: the first, which runs from equipment providers to technology buyers, and the second, which runs from technology buyers to equipment providers. Second, the buyer will incorporate the technology into their distribution chain, which will affect their customers and suppliers.

Significant organisational changes, such as the restructuring of supplier relationships to more collaborative forms, according to Bessant (1994), are required for the technology to reach its full potential. It is expected that the adoption of additive manufacturing technology will necessitate greater coordination between suppliers and customers. Vendor support throughout the implementation phase has long been recognised as crucial to project success, but it is now becoming much more so. It has been established that the level of complexity of technical innovation is directly connected to the intensity of user-supplier contact processes (Zairi, 1998). As a result, vendor assistance is advised as a critical component of AM implementation.

A prominent feature of the present additive manufacturing market is the tendency for machine vendors to move into material producers (such as the powders utilised) after installation. This is partly owing to the technology's infancy, but it's also most likely a tactic on the side of the machine supplier to ensure future business. Furthermore, decisions will be made on where to locate manufacture, as the lack of tooling requirements may allow assembly to be distributed according to demand regions, as the only inputs necessary for production are, in theory, CAD data and raw materials.

4.2.3 Data Analysis

Company A, which was founded in 2000, is a leading SLS and Direct Metal Laser Sintering (DMLS) product supplier in Europe, specialising in the fabrication of numerous and functional metal rapid prototypes, aesthetic models, and low-volume production components for industries such as aeronautics and aerospace, automotive, dental, medical, FMCG, marine, defence, pharmaceutical, and aerospace. The organisation took the first steps toward building a DMLS capability four years ago this month. In this case, the informant was Company A's Chief Executive Officer (CEO), and the investigation was backed up by interviews with personnel from the equipment vendor. The company's initial concentration as a polymer additive manufacturing expert was on the fabrication of prototypes for external customers. Because of cheaper process costs and overhead charges for higher volume production, the focus has shifted from consumer to industrial applications with the advent of metal-based technologies. Final thoughts: the interviewee was directly involved in the implementation of DMLS technology and could be considered the project champion; the interviewee believed that metals-based processes were critical to future success; and, when discussing production applications, DMLS technology was frequently mentioned as the processes that provided the most significant benefits.

4.2.3.1 Company strategy

The company's long-term goal is to become the largest provider of SLS and DMLS components in the European Union. DMLS was adopted at Company A as a result of a number of different factors and circumstances. The CEO's assessment of the benefits of technology is one of the most significant components of the deployment process. The CEO recognised the potential for competitive advantage that could be gained via investment in innovation and technology, even though technological innovations were still in their infancy at the time of his vision.

Company It's possible that changes in the RP sector affected A's decision to invest in DMLS, despite the fact that the company was formerly known as an SLS specialist. Over the last few years, many businesses have brought this expertise in-house, lowering the amount of work they must outsource to specialists like Company A. As technology has progressed and become more complex, many organisations have sought to bring this expertise in-house. However, while this transition has had a significant impact on the firm in some regions, it has had a less significant influence in others, and while demand has decreased, it has not completely disappeared as a result. Although it has achieved significant success, the case company is faced with the challenge of demonstrating its production capability in order to maintain the business benefits of the technology.

Company this means that the organization's strategy is highly influenced by its organisational predecessor, which has a research and development (RP) rather than a production-oriented base. According to the source, it would have been preferable if the firm that added it in had been a machining company rather than a fast prototyping company aspiring to become a legitimate aerospace or whatever provider.

Company According to this theory, A's approach to additive manufacturing deployment is influenced by a variety of factors, including the company's culture, the lack of a well-established client base, and the company's manufacturing capability. As a result of this seeming inefficiency, they've developed expertise in "a specific style of design and application development." Because they carefully sought for and developed parts that are compatible with the DMLS methodology, they were able to overcome this problem despite the fact that the company established a workshop to accommodate the process. According to the source, it is much more profitable to design the part in such a way that you don't have to make any alterations after you've completed it; therefore, you design the part in such a way that no modifications are required, and if you can do that, it is much more profitable and much more quickly completed.

As a result, this is the primary in-house capability of the organisation. Given the significant amount of design effort required as a result, production downstream may suffer while productivity upstream may increase as a result of the design issues. The informant stated that it is difficult to forecast where the next work will come from or how the DMLS product market would alter over time in the current DMLS product market because it is unpredictable. The market climate remains highly unpredictable as a result, especially considering the relative young of both technology and markets at this point. With a few exceptions, the informant asserts that the industry's understanding of the process is far inferior to that of the users in general. Demand for lighter planes and more energy-efficient technologies is frequently influenced by environmental legislation, and aviation is one of the outliers in this regard. These firms are being targeted by Company A because they require less education on the benefits of additive manufacturing and because the components they make are better suited for it than those produced by other businesses.

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4.2.3.2 AM technology

AM benefits, according to the CEO, must be addressed throughout the product life cycle, making it difficult to educate customers about these potential prospects. The company's focus on Aerospace applications reflects this. Over the course of a product's life cycle, the ability to reduce part weight through the design freedom given by additive manufacturing technology can result in significant cost savings for aeroplane component manufacturers. This is best demonstrated by the company's main in-house skills for additive manufacturing process design and application development.

The most major trade-off for the case firm was the cost of the machine, which limited the company's potential to increase in-house DMLS capacity. Aside from high process costs, which are mostly due to the slow pace at which components are made, the CEO mentioned high product costs as another trade-off that reduces DMLS's potential market size. However, as the informant points out, these viewpoints may change as technology advances.

Despite the fact that the company commits a large percentage of its resources to aerospace application development, the company has been forced to examine alternative industries during this certification phase due to the industry's certification requirements. This is partly due to a lack of technical standards for additive manufacturing techniques, which has resulted in longer certification timelines for commercial aviation safety-critical parts.

4.2.3.3 Organisational change

Because the company is a small business with no outside funding, it lacks the financial resources to invest in technological advancements and research and development, posing a barrier to expanding capacity and developing new industrial applications. Using RP" to fund RM research and development efforts is one way to overcome these challenges. Company A is experiencing a skills and experience deficit in the traditional metalworking and aerospace production flow. The CEO described the DMLS implementation production manager's role as "much more specialised" than the SLS implementation production manager's role as "one where this is most clear," and the result could be interpreted as an organisational feature of RP businesses transitioning to RM, as evidenced by a knowledge and skill gap in manufacturing applications.

Because the knowledge structures that employees use to perform tasks and produce social behaviour were developed, discovered, or evolved in the setting of an RPC environment, a company's experience with RP has had an impact on its organisational culture. When working in a rapid prototyping environment, the CEO notes that the goal is to "get components out quickly and at an acceptable quality." When dealing with change, speed is likely to be a valuable organisational asset, and quick turnaround is critical to success. On the other hand, cost and quality control are likely to be significant variables in manufacturing success. The organisation benefits from short response times in this unpredictable environment due to its centralised organic structure, with the CEO as the principal decision maker, but it is also prone to individual errors of judgement. Design engineers and engineers, as well as a production manager, are among the members of the team. Since it was first made as a copy of the original plastic RP side structure, the structure has evolved significantly. Because there are no antecedents, the CEO believes the organisational structure will "likely be worked out as they go along," rather than before.

4.2.3.4 Operation Systems

The organisation focuses a considerable percentage of its time spent with customers to customer education. This training will most likely concentrate on the capabilities and limitations of the process, as well as how to plan for process difficulties in order to reap the benefits of technological advancement. In this case study, it is discovered that the quotation technique is a time-consuming and resource-intensive operation.

RP, on the other hand, has a more straightforward quotation procedure because the process chain is more straightforward (discussed below). Furthermore, there is no need for part re-design in RP, and cost is not necessarily the deciding factor in orders for one-offs and small batch sizes, when delivery speed is of greater importance. The complexity of the process chain, the design of the process, and the reduction of costs must all be considered during the quotation stage for RM.

As part of the case study, it was also pointed out that the process chain in RM applications was in need of significant improvement. It is important to perform heat treatment, finishing, and measuring operations in order to produce high-quality manufacturing components for RM applications, which increases the length and complexity of the process chain significantly (when compared to RP). According to the CEO, in this environment, it becomes "a whole workshop coordinating." This rise in complexity can be attributed in part to the idiosyncrasies of the DMLS process, which demand the removal of support and other post-processing measures. Second, when comparing production parts to prototypes, the quality control requirements for production parts are higher than those for prototypes. In addition to excellent process design and optimised process planning approaches, as previously indicated, they can also help to reduce the amount of downstream processing that occurs.

4.2.3.5 Supply chain of AM

Due to their competence in Rapid Prototyping, the case company does not have a well-established customer base for manufacturing metallic components. In comparison to a trusted components supplier, acquiring new clients necessitates a significant expenditure of both time and money on the part of a machining company. Machine suppliers' restrictive strategies were explored, including those employed by machine suppliers to limit the sorts of powders that might be processed and to lock down machine parameters. As a result of these acts, the company's material variety is limited, limiting the number of potential commodities and markets it may offer. Due of a lack of competition in the marketplace, material costs remain high due to the supplier's tight control.

Another sort of supplier limitation is the locking down of process parameters, which is "annoying" to high-end customers since it "annoys" them. As a result, the company's R&D efforts are likely to be hampered, as it will be unable to experiment with process parameter optimization activities. This issue generates a reliance on the machine vendors' R&D operations as the systems become increasingly inaccessible to operator change. According to Company A's CEO, machine vendors are astounded at how little they can learn from Company A's machine development experience. Some providers are more receptive than others when it comes to making them ready for production, which he emphasises in his address.

Assuming that a client base has already been established, or at the very least that there is awareness of the need for products based on location, the option of locating production based on demand is not viable; in this case, manufacturing will continue to take place in a single, centralised location. Furthermore, post-processing and supporting equipment (such as CNC machines) requirements limit the manufacturing system's flexibility in terms of location. As a result, this is likely to continue for a while, at least until additional machine advancements lessen the need for component post-processing and additive manufacturing approaches net-shape fabrication.

4.2.4 Summary of case study 2

As an example, the example company has demonstrated its ability to provide support for the study methodology and constructions, as well as insight into the correlations between variables. During the analysis phase, some attention was placed on determining the explanations for the observed characteristics, as well as those that would be common to AM implementation in a certain circumstance and therefore a source of a potentially more generic solution (improving external validity).

Some of the RP convertor's management and implementation issues, as well as potential cures and solutions, have been recognised and addressed. In order to write well, you must first comprehend the nature of the case study offered in this paper, as well as the unique event under investigation. The study's scenario is that of a company with a history of prototyping that wants to use additive printing as a new manufacturing process for new product development. The purpose of the situation at hand is to determine the amount to which the framework components have an impact and how noticeable they are. For a business with a traditional machining pedigree and a presence in the aerospace supply chain, the difficulty of altering an R&D culture and building a reputation as a manufacturing company will likely be easier. The difficulty of understanding new design restrictions for additive manufacturing, as well as the hurdles of transforming a traditional manufacturing culture, are likely to have a significant impact on the implementation's success. As a result, future research may focus on comparing methods in these various contexts, as well as mapping these techniques using the criteria established in this framework as a starting point.

The framework was only tested in a single case study, which is one of the study's drawbacks. Single case designs are fragile, according to Yin (2003), and single case research reduces the generalizability of the data, models, and theories developed, according to Voss and colleagues (2002). However, while these hazards persist in multi-case research, they have been significantly reduced, and future study may focus on more case studies of AM implementation in other organisational contexts and supply chain scenarios to increase the framework's generalizability. As the number of implementers grows, researchers will have more access to a wider range of examples. Although there is unlikely to be a single optimum method for implementing AM processes, this study has provided insight into the challenges and proposed a framework to aid managers in implementing this potentially disruptive technology class.

4.3 Case Study 3: Performance Monitoring and Control for an Additive Manufacturing Factory - A Case Study in the Aerospace Industry

4.3.1 Overview

This case study describes the design and implementation of an additive manufacturing factory for the production of complex parts for the aerospace sector, which was performed in collaboration with an industrial enterprise. Based on our findings, we believe that the construction of such a facility poses a number of AM-specific issues that necessitate the creation of customised solutions. Controlling the quality of parts, rather than other common difficulties like cost and delays, is the most crucial aspect of performance for an AM-based factory at this early stage of the industrialisation process of AM technology. Furthermore, unlike typical non-additive production systems, this quality component should be approached differently: monitoring the entire learning and adaptation process of operators becomes the most critical issue for achieving optimal operational performance quickly. A number of actions must be made to monitor this learning and adaptation process, and these actions are noticeably absent from published results and well-established best practises. The goal of this paper is to provide useful insight and suggestions into some of the operational challenges that businesses are likely to face when beginning on such initiatives, by highlighting major concerns that must be addressed and broad characteristics of the solutions that can be applied.

For a long time, manufacturers have been tracking and controlling their performance, and best practises have been developed. Given this extensive history, it's easy to fall into the trap of thinking that monitoring an additive manufacturing plant's performance is a simple task that should be based on well-established procedures and technologies. As we will demonstrate, old performance issues are still relevant and important, but their interpretation has altered slightly, necessitating the employment of new performance standards in their place. In order to better grasp which parts apply and which elements need to be reinterpreted in an additive manufacturing industrial scenario, the next section provides a brief historical overview of key performance indicators for manufacturing systems.

A strong trend for product diversification occurred in the second half of the twentieth century, quickly becoming a key competitive feature (Le Masson et al., 2006). The rate at which new products are introduced has accelerated. These new criteria emphasised the importance of product quality as a critical component of performance for businesses operating on tight budgets and timelines. Product and process unpredictability is, in fact, a primary effect of product diversity, which can lead to considerable productivity and reputation losses. Product diversity raises costs and delays because machinery and equipment must be changed on a regular basis.

This distinction blurs in an AM industrial environment since the new generation of 3D printers requires a complex skill set that can currently only be handled by operators with engineering backgrounds and even PhD degrees. Furthermore, most designers are unfamiliar with designing for additive manufacturing, necessitating new jobs for AM" plant operators to assure part feasibility. This is especially true because designer software and printer software are not yet completely interoperable, demanding additional verification and conformity control activities, as well as the management of feasibility and quality difficulties.

Because of this fuzziness, AM production operators' learning and adaptation processes are a major bottleneck and must be closely controlled. In some ways, this comprises a combination of early rationalisation projects (such as Taylor's scientific management) and later ideologies (such as lean or agile manufacturing) that prioritise human-centric aspects of factory performance control (Gunasekaran, 1999).

4.3.2 Conceptual Framework

Consider the situation of an additive manufacturing factory that will print complex metallic parts for the aerospace industry and is designed, developed, and operated by a world-leading industrial business, which we'll refer to as company X in this example. Both a functional production system with traditional manufacturing performance goals and a centre of expertise on additive manufacturing, with the purpose of developing knowledge and skills in the technology, are expected to be achieved at the same time at the site.

The multi-unit production mix of the factory is a dimensioning feature, and it includes the following characteristics:

- High degree of diversity:

Each piece is assumed to be one-of-a-kind (or manufactured in a limited number of samples).

- High complexity:

  Parts of high value and complicated shapes will be produced in order to take advantage of the geometric freedom afforded by additive manufacturing technology to its fullest extent.

- High volume:

  After a few years, the plant should be able to produce between 10 and 50 pieces per day on a permanent basis, depending on the product. The initial manufacturing rate target is closer to 5 components per day than 10 components per day.

It was conducted between February and May 2016 as part of a mission managed by the consulting firm Manza Consulting for company X, a large industrial company. The research was conducted on a qualitative basis (whose name we will not reveal for reasons of confidentiality). Collaborative management research (Shani et al., 2008) is the foundation of the current investigation, which was carried out by researchers and practitioners in order to create actionable knowledge for the organisation and new theoretical models in management research (David and Hatchuel, 2008). The study was carried out by two management science researchers, two operational performance experts from Manza Consulting, and members of the enterprise X steering committee.

The purpose of this study was to examine the architecture of additive manufacturing facilities, analyse the specific concerns that arise as a result of the process's innovativeness, and make recommendations on how to generate acceptable answers to those obstacles. When Manza Consulting's client company sought to better understand and foresee the operational problems they would face once the plant was up and running, they were looking for information that would help them make better design decisions. From an academic standpoint, an additive manufacturing plant is an intriguing and understudied research object. Organizational aspects are an interesting complement to the existing literature, which is predominantly concerned with process characterization. For the management research community, it represents a new type of factory whose characteristics must be better described and understood; for the additive manufacturing research community, it represents a new type of factory whose characteristics must be better described and understood.

4.3.3 Data analysis

Researchers can have access to a vast amount of data and alter their investigation to make sense of the situation using the collaborative management research approach. Data was collected using a range of methods throughout our interventions, including interviews with key players (such as AM specialists and enterprise X actors), a review of existing literature and enterprise X documents, and participation in regular meetings and working groups. The study is based on this extensive data set, albeit due to confidentiality concerns, we are unable to reveal all of the facts at this time.

They used this data to conduct a top-down and bottom-up analysis to examine the relationship between performance and the information system. They highlighted and explained several major operational concerns that need be investigated in order to ensure that the factory's performance improves using the top-down technique. They focused on identifying potentially needed and available data at various phases of the process, as well as how to quantify and arrange this data to address the AM-specific difficulties previously mentioned, using a bottom-up approach.

Metallic powder and a digital mock-up (CAD file) that describes the item to be printed (along with quality specifications, such as target geometric, mechanical, and physical attributes) are accepted as inputs, and the manufacturing process must return a printed part that meets the intended specifications. This approach can be divided into four parts, as shown in the diagram above.

First, CAD pre-processing: an operator receives and stores CAD files from clients, confirms their viability on additive manufacturing machines, and then converts the CAD file to a print-ready state. 2. CAD post-processing: a technician converts CAD data to print-ready formats (e.g., STL format).

The operator must now parameterize the printing process in the second stage, which is the most critical and difficult step because all decisions made at this point have a significant impact on the printed object's final quality. Step three: The position and orientation of a component in the build chamber must first be determined; then, support structures must be added to the original part (to prevent deformations during the printing process); the component's digital model must be "sliced" into many layers; and finally, the laser's parameters must be set (most importantly: scanning path, speed and intensity of the laser).

Third, before beginning the print, the operator double-checks that the powder container on the AM machine is filled with the necessary powder for the construct. After that, he can begin printing and wait for the item to be assembled layer by layer as it is built. The powder in the machine's build chamber is entirely depleted after printing, with the printed part occupying the chamber's centre. First, the operator must remove all of the powder from the mix, which will then be recycled for future builds. This is performed with the use of a specialised vacuum system. Finally, he can remove the part and supports from the build chamber once they have been produced on the printing platform.

After that, there are a few more changes to make to the document's printed component, which is the final stage. The printer must be separated from the printing platform and any supporting structures utilised during the printing process. Depending on the item's final specifications, post-processing techniques such as heat treatment, surface finishing, precision machining, and so on may be necessary. Due to the intricacy of such procedures, the bulk of additive manufacturing plants will need to obtain their entire spectrum from outside in order to maintain a network of post-treatment vendors.

4.3.4 Summary of Case Study 3

As additive manufacturing is presently moving from the prototype stage to the manufacturing stage, high-performance additive manufacturing facilities must be designed and built. As industrial firms continue to engage in this industrialization process, the need to investigate AM-specific operational management difficulties and provide cost-effective solutions to assist practitioners in overcoming these obstacles becomes more obvious. We presented findings from a collaborative management study undertaken in conjunction with a world-leading corporation in the aeronautics industry in relation to a cutting-edge industrial situation. We claimed that a factory's ability to control the quality of printed components and swiftly adjust to a diverse production mix is the most essential factor in its overall performance. For the development of these abilities, a productive learning process based on two crucial components is required: highly competent operators and a customised information system that maintains track of the factory's critical points of attention. We created a list of operational challenges that arise at various phases of the production workflow, as well as some consequences for the architecture of this information system, based on our industrial field experience. In order to deliver useful insights to current and future managers in the additive manufacturing business, further research is needed. We urgently need to improve our grasp of the complexities of managing operations in this type of environment, where procedures, equipment, and standards are all in the early phases of development and have yet to be defined.

CHAPTER 5

CONCLUSION

5.1 Conclusions

Based on the case studies, Additive Manufacturing is a method of producing objects by layering them together in a custom design. Using CAD, such as 3D scanning, a 3D model can be divided into discrete layers, each of which contains the tool path code needed by a 3D printing machine at the time of creation. Depending on the software, the machine starts a parallel process that repeats the model from the bottom to the top until the item is complete, at which point the machine stops. Affection for 3D printing, also known as additive manufacturing, has captivated the public's imagination, inspiring fantasies of 3D printed aircraft and bio-fabricated organs. These objectives are still a long way off, despite the fact that innovation ensures assembly's final fate and has already had a huge impact on our immediate environment, which has already had a significant impact on our immediate environment. Whether the effects are immediate or long-term, 3D printing will fundamentally alter the way things are done in the future.

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APPROVAL PAGE

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NAME OF AUTHOR : SHARVIN JAGANATHAN

The undersigned certify that the above candidate has fulfilled the conditions of the project paper prepared in partial fulfilment for the degree of Master in Management.

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