Factors Affecting the use of Additive Manufacturing in production

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Zásady pro vypracování

Introduction
Define the objectives and the application methods used in the master thesis.
I. Theoretical part

- Compile literature review focused on types of AM (3D-Printing) and its application in production.

II. Practical part

- Analyse the factors affecting the use of AM in production by benchmarking examples from different industries.
- Propose a systematic methodology for applying AM in new applications.
- Perform cost and risk analysis of the proposed solution.

Conclusion

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ABSTRAKT

Aditivní výroba je běžně používaná technologie při vývoji nových produktů. Je to nová technologie ve výrobních aplikacích v průmyslu. Cílem této diplomové práce je prozkoumat aplikaci AM ve výrobě v průmyslových oborech a analyzovat, zda je vhodná pro implementaci ve výrobě v jiných průmyslových odvětvích, zejména v hromadné výrobě spotřebního zboží. V práci bude uveden přehled technologií a prozkoumány faktory, které ovlivňují uplatnění AMT ve výrobě. V praktické části je uveden kompletní plán realizace. Proběhly také rozhovory se společnostmi, které aplikují AM ve výrobě, aby bylo možné prozkoumat výstupy práce a získat zpětnou vazbu od odborné strany.

Klíčová slova: Aditivní Výroba, AM, 3DP, Rapid Prototype, RP

ABSTRACT

Additive Manufacturing is a commonly used technology in new product development. It is a new technology in production applications in industries. The objective of this thesis is to investigate the application of AM in production in industrial fields and analyse whether suitable for implementation in production in other industries, especially in the mass production of consumer goods. The thesis will overview the technology and carry out the factors which affect the application of AMT in production. The practical part gives a complete implementation plan. Interviews with companies that apply AM in production take place to examine our plan and get feedback from the professional side.

Keywords: Additive Manufacturing, AM, 3DP, Rapid Prototype, RP

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I hereby declare that the print version of my Bachelor's/Master's thesis and the electronic version of my thesis deposited in the IS/STAG system are identical.

Moataz Lashin

CONTENTS

INTRODUCTION

Additive Manufacturing has been in industry for more than thirty years. Recently, the related research made the technology become cheaper and faster as before. AM Technology is used for producing physical products from drawings which are designed by Computer-Aided Design CAD software. AM will affect the current technology of manufacturing and allow companies to develop a new business model (Niaki, Nonino, 2017). AM is evaluated as an expensive manufacturing technology for mass production however it has a good opportunity to give to the manufacturing. When AM is compared with the conventional manufacturing, it is characterized as the ability to efficiently create a very complex part with minimum waste. The waste may be in material scrape or assembly time for the subassembly parts. There are different types of AM machines or 3D printer start from professional use to non-professional for personal use. The machine specification depends mainly on the application of the machine and required products specifications which affect the machine price. The differences between AM and other manufacturing process(Horne, 2020) (Horne, 2020):

The parts are produced layer by layer. Complexity of internal and external geometry can be easy produced when compared with traditional means of production.

Raw material added rather than subtracted. The material consumption during production is less than that needed for other manufacturing technologies. However, it needs support structure.

The part production done without the need for production tooling. Design customizations or modifications can be done very fast and without investment in tooling.

Day by day AM technologies become more efficient fast, available, and affordable. However, it is not yet efficient in all industrial applications as other conversational manufacturing CM. AM empowers industries to enhance business value. AM is creating its way into production engineering in industrial business. It becomes a current trend in production companies because of AM benefits. It can be stated in industry 4.0 while applying in manufacturing business (Praveena et al., 2022). AM techniques help the manufacturing companies to produce parts with extremely complex lightweight product added values. Additive technologies can be relatively more economic to reduce the operating costs of the company, especially in saving of start-up and lead time of new products. These benefits lead the enterprise to increase competitiveness and efficiency. One important role for gaining

profit by implementing AM in production is to choose the right parts to produce in the product.

When we have a deep dive into home appliances business, we find that Egypt imports raw materials and components for production, whether in the form of complete product. The high rate of population growth is considered as an important factor in increasing the demand every year. We cannot disregard the fact that local brand names are considered as premium and being sold at a significantly higher price level than the exported or unknown brands. As the important of this business, the study will go deeper for the use of AM in it.

The study starts with a literature review of AM and AMT descriptions. Then it will illustrate AM application in industrial sectors. Followed by the factors affecting the application of AM in production and the value-added in industrial fields regarding operations, and technical issues. Finally, provide systematic procedures and tools for applying the AM production.

This thesis consists of two parts theory part and an analysis part. The theory complies give complete overview and literature review of AM technologies, types, terminologies, manufacturing applications, and factors affecting the production. Then, discuss the application in the leading sectors and the advantages of the use of AM in each sector such as the aerospace, automotive, Healthcare and consumer goods sectors. Practical evidence of the value of applying AM to the enterprise, the positive impact on the economy, advantages, and challenges. Analyse the factors affecting the use of AM in production by benchmarking examples from different industries. delineates recent advances in additive manufacturing applications in the industry. The factors affecting the application in production and barriers facing the spread of AM in industrial and manufacturing organizations.

The analysis part proves the implementation process for AM Mass production. AM fails to produce the standard parts in large production volumes based on specific designs, but it is a good and acceptable tool for mass customization. Mass customization is like mass production although the production process can be changed for small batch according to a specific product design. Analysis part give a cost comparison between AM and CM. it covers part cost and investment required with the compared with CM.

In the future, AMT will be the standard production method and used to add to the product feature according to customers direct choice. This will become significant when the mass production concept changed into mass customization according to customer need.

OBJECTIVES AND METHOD METHODOLOGIES

AM transformed from prototyping to production in almost all industrial sectors however the applications in mass production industries such as home appliances is still little. While AM could shift mass production into a new era of customization of products, there are barriers for application of it.

The aim of the study is to capitalize the benefits and examine the barriers of application in productions then develop a methodology for implementation of additive manufacturing to build a succeed business model and cover the business needs of manufacturing and production. To be able to develop the methodology I did overview of AM technologies and analyses the factors that affecting the product after applying AM in production. Examine and enhance the proposed implementation methodology in production using real case studies.

To perform our study successfully, the research questions are:

- What is AM and the application of AMT use in manufacturing organization?
- What are the key factors affecting the implementation of AM in production?
- How do those factors impact the implementation of AM in production?
- What is the methodology for applying AM in production and suitable analysis required?

The main objectives of the master thesis are:

- Give overview of the AM technologies and analyses the factors that affecting the product after applying AM in production by Compiling a literature review focused on types of AM and its application in production.
- Illustrate and analyse the factors affecting the use of AM in production by benchmarking examples from different industries.
- Develop a systematic methodology for applying AM in production new applications. Propose a methodology for succeed business model and cover the business needs of manufacturing and production.
- Verify the proposed methodology on real production case studies and enhance the proposed implementation methodology in production using real case studies. Proof the result of feasibility with cost and risk analysis of the proposed solution.

In order to answer this thesis research question and reach the objectives, a research methodology should be used in thesis work.

The theoretical part consists of general definition AMT and its parameters and the process. description of different methodology of AM and which product can be produced by AMT and the available materials. Then show the different sectors where AM became a common production tool in it. Moving on theoretical part by illustrating the implementation methodology for applying AM in production and its aspects. Turning to analytical part, starting with the current state of AM in industrial companies and especially in home appliances manufacturing sector. Moving on analysis, by analysing the AM application in different industrial sector, it will be clear the factors affecting the application of AM in production. describe the problems which can be solves. then the implementation methodology which cover the organizational and product aspects. Home appliances manufacturing companies in Egypt will be selected for collecting date. Interviews with the companies' managers will give the current state situation as a primary data. The interview will be done during one-to-one meeting while visiting the company. The interview questions can be found in the appendixes. Real data will be obtained for different parts suitable for applying AMT. the needed date can be collected from different departments in the companies such as purchasing and financial departments.

In the project result parts, implementation procedures contain economical assessments are introduced. Indications of the feasibility of use of AM in production will be quantitative and qualitative indications. Quantitative indications come while collecting data which will be analysed and calculated. Qualitative indications appear in other benefits could be added to the business when we apply AM. Business tools will be used in project parts. Cost assessment break-even analysis will be done for the parts in case studies and PEST Analysis as well. Risk analysis using RIPRAN methodology will be done for the implementation.

I. THEORY

1 LITERATURE REVIEW

Additive Manufacturing AM Technology, also known as 3D printing, can produce physical products from drawings which are designed by Computer-Aided Design CAD software Additive Manufacturing AM has different terms to describe it such as 3D printing 3DP, Rapid Prototyping RP, Rapid manufacturing RM, and Rapid tooling RT. AM enables a high level of creativity and increased product design freedom without conventional manufacturing constraints. AM could be considered a third industrial revolution because it changed the manufacturing market. (Piazza, Alexander, 2015) . AM is still contributing to Industry 4.0 by integrating information technology and artificial intelligence with the modern manufacturing skills and in mass customization. (Dilberoglu et al., 2017)

1.1 Introduction to Additive Manufacturing

Additive Manufacturing AM is the term describing the process for adding and joining the material together, usually layer upon layer, to create a physical part from 3D drawing as opposed to Conventional Manufacturing CM such as the subtractive method. (ISO/ASTM International, 2015). Figure 1 illustrate the general process of Additive Manufacturing Technology AMT. start from 3D modelling using CAD software then generate a special file format (.stl) to be readable by printer software. the printer software slices the drawing then send to the machine for production.

AM need finishing post-processing such as grinding or sandblasting and coating such as painting or vacuum metalizing.

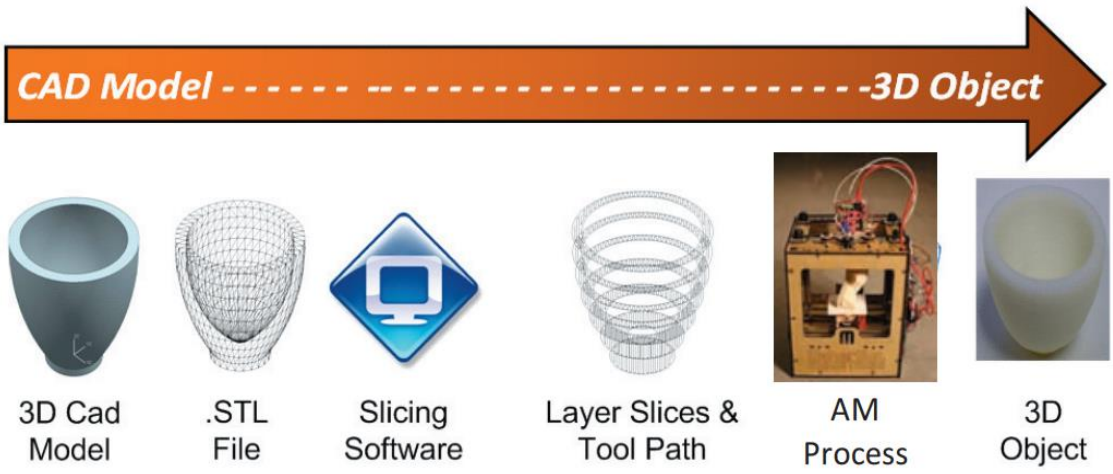

Figure 1 Additive Manufacturing process. (Campbell et al., 2011)

The AM has three phases in manufacturing. The first phase of the application is in new product design prototypes. AM succeeded to produce cheap fast functional and aesthetic prototypes. AM has an excellent value add in the new product development NPD process. It reduces the time-to-market as well as gives the company a high level of project control compared to the classical route of development. It accelerates the design and changes with reduced costs. The second phase is to create final parts for end usable product or production tooling manufacturing. The third phase is more effective in production and manufacturing. It enables the consumers to have their 3D printers produce their pieces (Niaki, Nonino, 2017).

Part orientation

Part orientation during the printing process is an important parameter. The part orientation affects production cycle time, material consumption and the part strength. Material consumption and build time for support structure needed for hold the next layer can be reduced by changing the part direction on the printing platform. Moreover, printing head travel time number of pieces produced at the same time. Some AMT is anisotropic so the strength or the part depends also on the printing direction.

Accuracy and Surface Finish

AM machine parameters and material used can improve the part quality and surface finish. Surface finish depends on the machine print speed and layer thickness. Moreover, it can be improved by powder molecular size and binder saturation. Machine resolution (dpi) and layer thickness μm define the dimensions accuracy and surface finish (Murat Aydin, 2015). Figure (2) shows the stair stepping which affecting the Surface finish (Milewski, 2017). Improving smoothness increase the cost but balancing is not important because post-processing give better surface (Jordan, 2019).

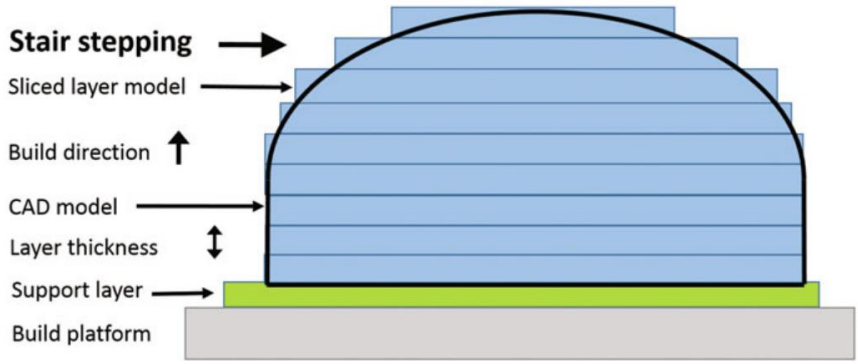

Figure 2 AM Part Surface Finish. (Milewski, 2017)

1.2 AM Technology Overview

It is necessary to know the different methodologies of AM and which product can be produced for and the available materials. The most effective way of categorization is to categorize the overview according to material: plastic AM technology and Metal AM technology. The most used techniques will be presented. Methodology description, machine specifications, and material range.

1.2.1 Plastic AM Methodology

Stereolithography (SLA)

SLA or VAT Photopolymerisation is building build a solid layer by focusing an ultraviolet laser beam to solidify a photocurable resin. Then the model platform moves down, and a new layer of the resin got solidified over the current layer. SLA is widespread use in the rapid prototyping RP also it was the first commercialized process. It produces a relatively good surface finish of polymer parts with different materials and post-processing options with the lowest lead time. However, the main disadvantages are the requirements of support which waste material and time for production and support removal and also changing the raw material needs a long time.

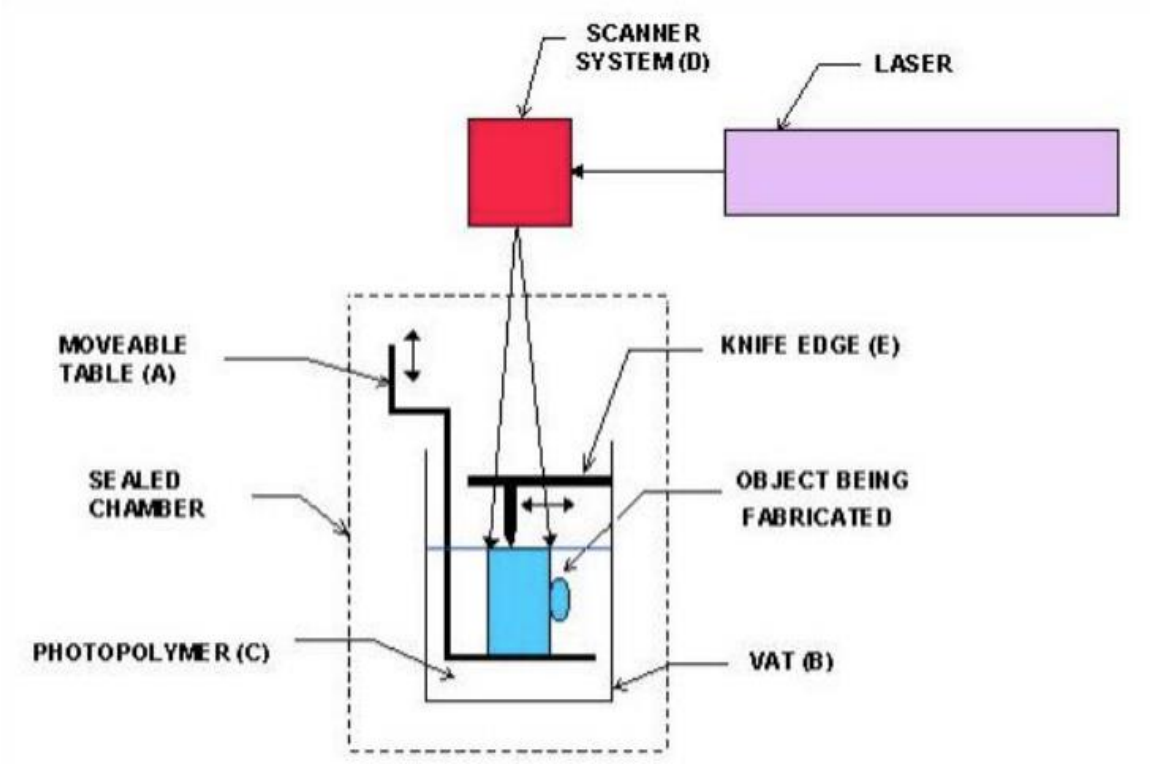

Figure 3 Stereolithography SLA (Aliakbari, 2012)

Selective Laser Sintering (SLS)

SLA melt a layering point by point to build a solid layer by focusing a laser beam on material powder. Then the model platform moves down, and a new powder layer is added on the top of the current one.

SLS can create polymer, ceramic, and metal parts with accurate dimensions. It can create any material which can be in powder form. However, powder granules' size and morphology affect the product accuracy, surface roughness and density. It is more suitable for a production run due to the material properties and stability. Furthermore, the unfused powder acts as a support for the next layer and can be reused which leads to low material usage. The material is more hazardous than SLA liquid.

The machine is relatively inexpensive and suitable for the prototype. The part size is limited. It has a large range of materials but it the lake of structural properties. No need for support structure because powder supports the following layers. This technology speed is relatively slow. High power consumption. Surface finish depends on material grain size. (Patel, 2019) SLS is applied in aerospace, military, electronics, medical and connectors industries.

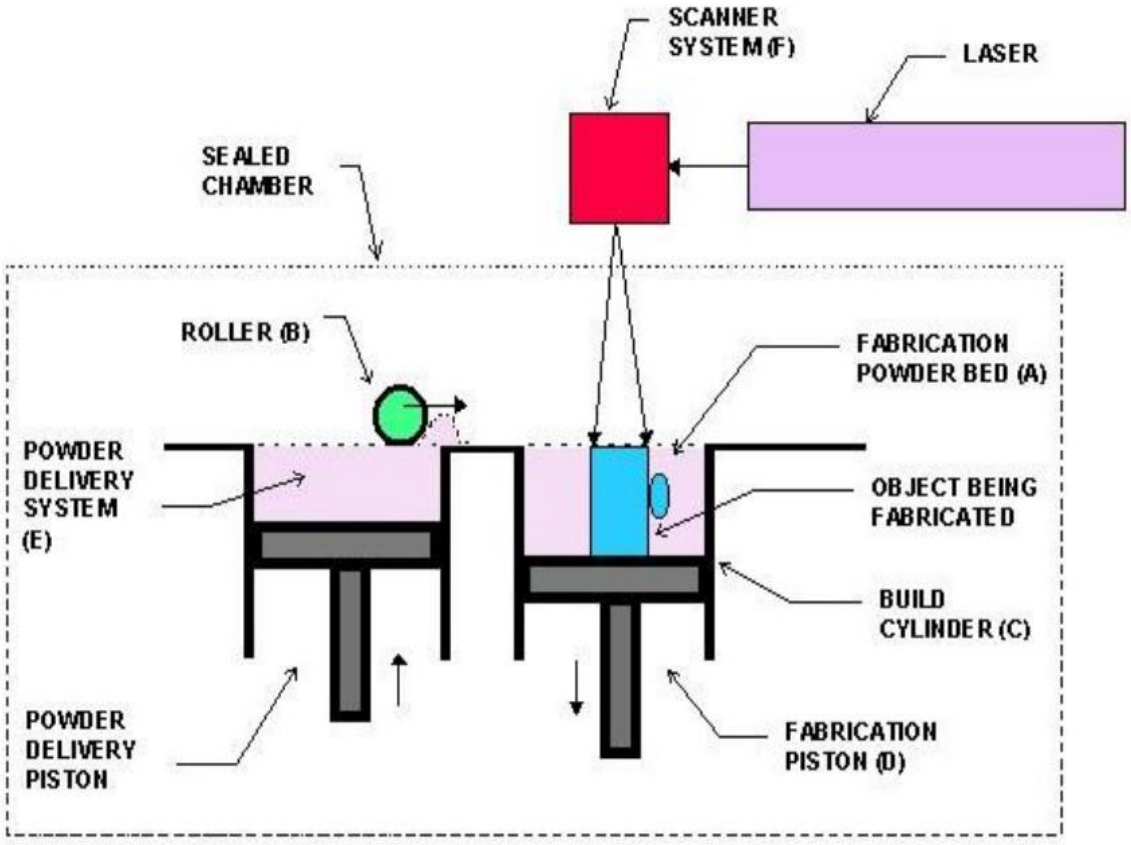

Figure 4 Selective Laser Sintering SLS (Aliakbari, 2012)

Fused Deposition Modelling (FDM):

Creating the model by extruding the melt material through a nozzle. (Patel, 2019) Easy to use, clean to use in an office environment, and low machinery cost. However, it is a slow operation. It is an expensive process. Low finish quality is bad and low printing speed.

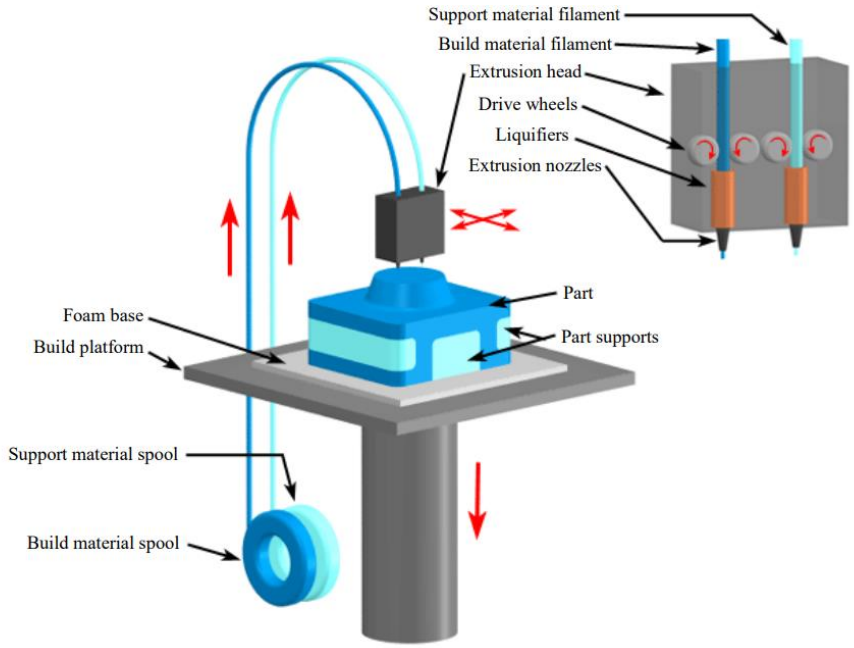

Figure 5 Fused Deposition Modelling FDM (Parupelli and Desai, 2019)

Three-Dimensional Printer (3DP):

3DP is Similar to SLS except ejecting a binder from an injection head for powder solidification instead of a laser. Material may be plastic, metal, or cement.

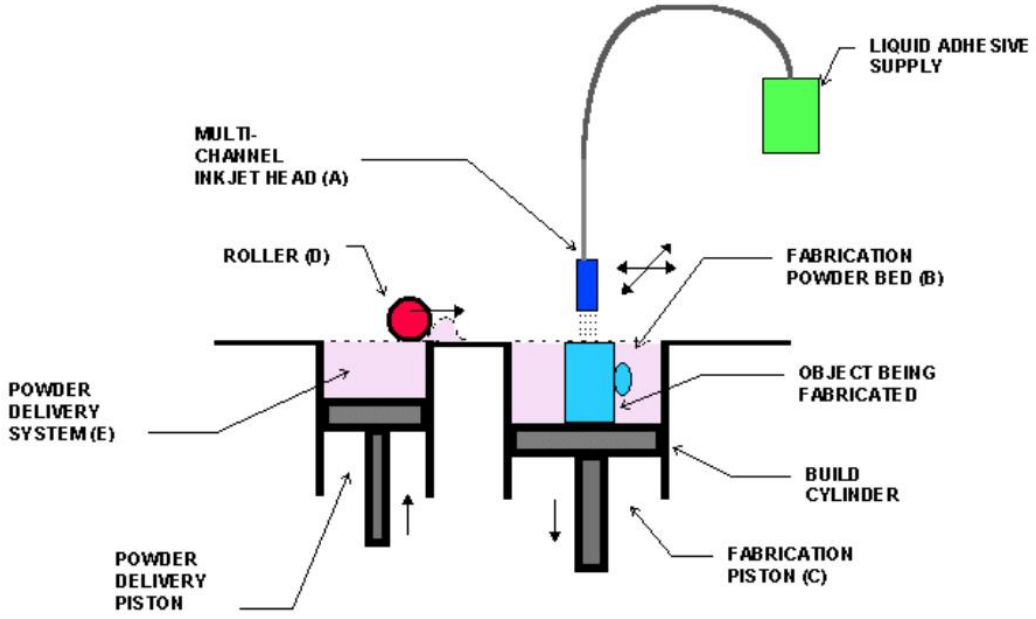

Figure 6 Three-dimensional printer 3DP (Aliakbari, 2012)

1.2.2 Metal AM Methodologies

Direct Metal Laser Sintering (DMLS)

DMLS is like SLS but it is only for the metals. The process needs to build a structure to support the next layers due to high thermal stresses generated during the build. The DMLS can produce any quantity from prototypes to large product volumes up to 20000 units per year and production tooling as well. The most used alloys are titanium. (Aliakbari, 2012)

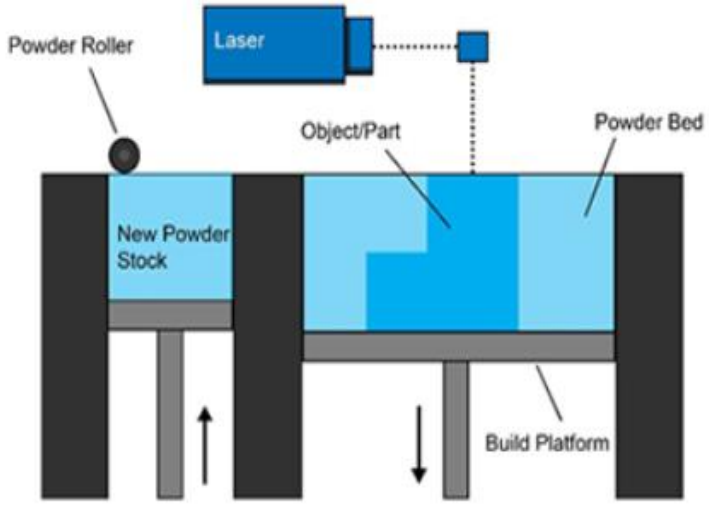

Figure 7 Direct Metal Laser Sintering (DMLS) (Patel, 2019)

Selective Laser Melting (SLM)

SLM uses a laser for melting metal powder molecules together. A layer of original materials l added to form the next layer of metal. needed heat treatment after the part is completed.

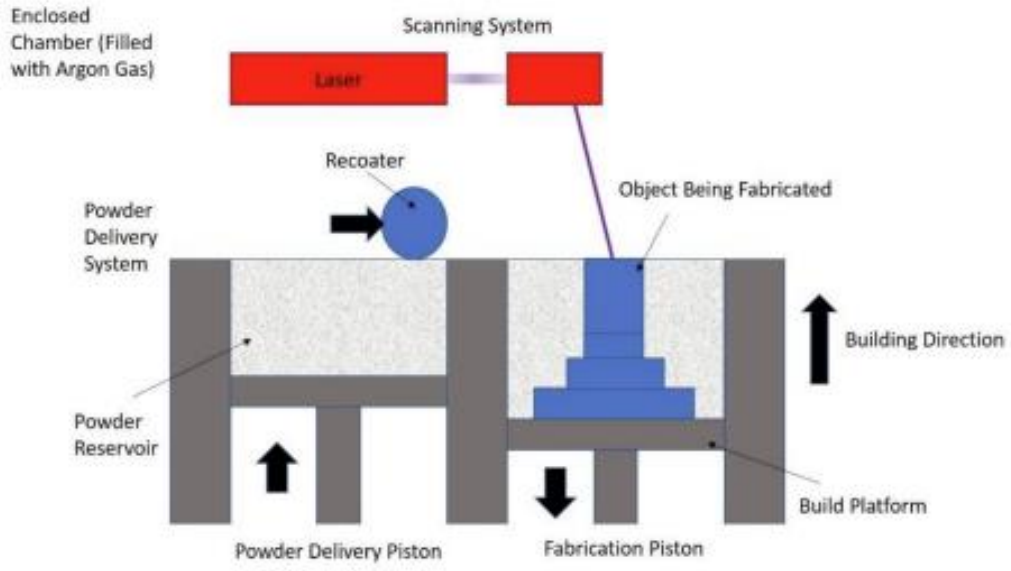

Figure 8 Selective Laser Melting (SLM) (Jiao et al., 2018)

Electron Beam Melting (EBM)

EBM is Similar to powder-based types. It uses an electron beam gun for powder solidification.

The advantages are increased speed and reduced thermal stresses. However, online y conductive metal powder can be used with and poor surface finish.

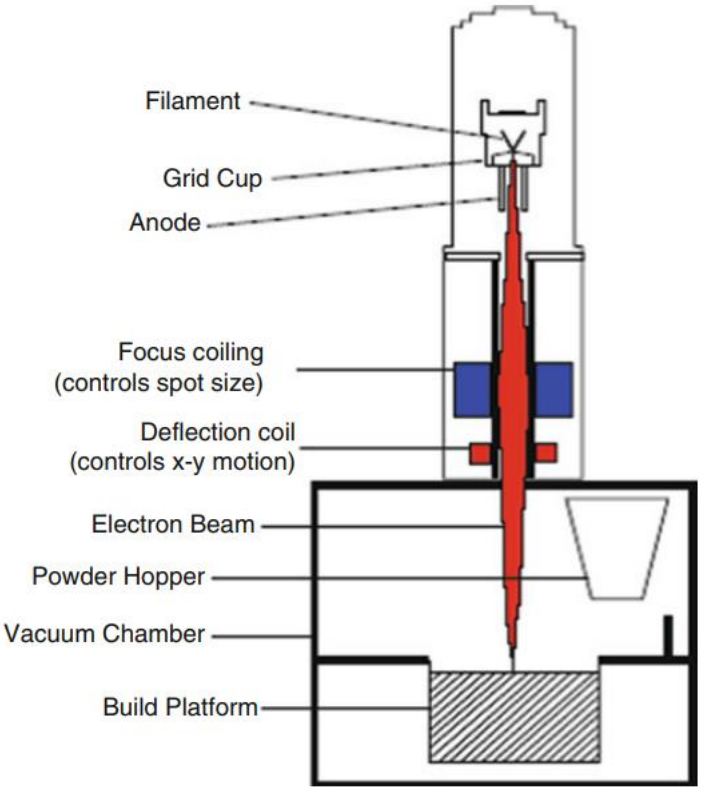

Figure 9 EBM Machine (Gibson, Rosen, Stucker, 2015)

Easy CLAD

Easy CLAD injects the metal powder into the nozzle. a laser beam to melt the powder at the nozzle exit. Gas is used to prevent oxidation.

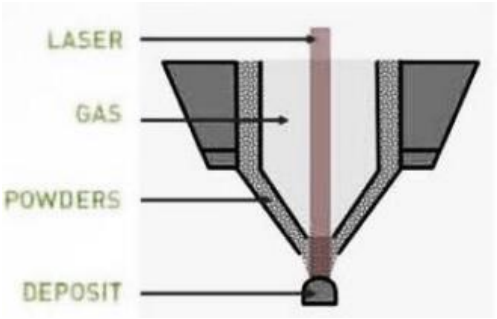

Figure 10 Easy CLAD (Aliakbari, 2012)

Laser consolidation

Nozzles for material feed are paced in the way of the laser beam.

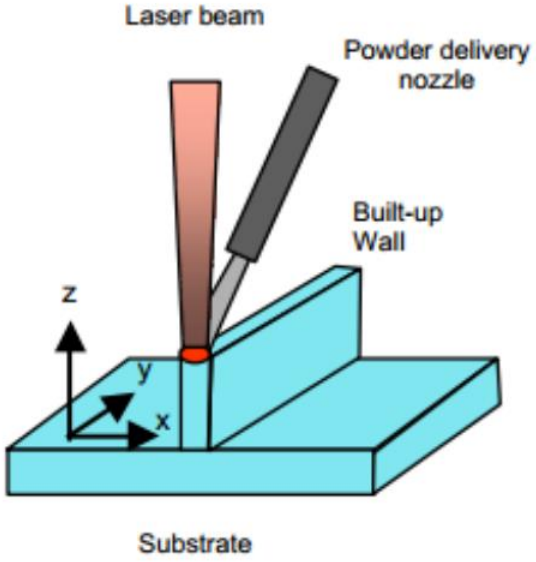

Figure 11 Laser Consolidation (Aliakbari, 2012)

1.3 AM Materials

Material selection is a very important step for applying the AM. Material choice has a significant impact on the part design for AM. (Giulia, 2020) There are different material typologies of material but the more important is plastic and metals.

Metal materials are widely used in industrial applications, such as aerospace and automotive. Metals can be Powder or in wire form for extrusion techniques. The common available metals are Aluminium, titanium alloys, nickel, stainless steel and tool steel alloys.

The most common plastic material is PLA (polylactic-acid) and ABS (Acrylonitrile-Butadiene-Styrene). PLA part is stronger than ABS part. PP (polypropylene), PC (polycarbonate), PET (polyethylene), PA (polyamide= Nylon), PS (polystyrene).

AM technology selection and machine selection is the first step before part design. It depends on the part application and material. Choose the right machine will affect the whole project inputs such as the investment and the part cost.

Table 1 contains a comparison between AM Machines with main features of the machines and according to building technology and the size of building platform. It contains available material and the suitable finishing process.

Table 1 Comparison between AM Machines (Source: Own processing)

Technology	**SLA**	**SLS**	**FDM**	**3DP**	**DLMS**	**SLM**	**EBM**	**Easy CLAD**	**Laser Consolidation**
Material Type	**Plastic**				**Metal**				
Bulk Material	Liquid	powder	Solid	Liquid	Powder	Powder	Powder	Solid	Solid
Maximum Build Size	650×750×550	650×550×750	914×610×914	254×381×203	250×250×325	250×250×300	200×200×350	1500×800×800	500×500×500
Build Rate	- cm^3/hr.	0.6–2.5 cm^3/hr.	2.54 cm^3/hr.	25 – 50 cm^3/hr.	0.12–0.48 cm^3/s	4 – 16 mm^3/s	4 – 16 mm^3/s	85 mm^3/s	- mm^3/s
Layer Thickness	50 – 125 µ	120 – 150 µ	127 – 330 µ	90 – 100 µ	20 – 80 µ	20 – 100 µ	50 µ	140 µ	- µ
Post Processing	Support removal Curing Sandblasting	Sandblasting	Support removal Sandblasting	infiltrated	Support removal Curing Sandblasting	-	Support removal Sandblasting	Sandblasting	-
Material	ABS PP PC PET	PA (Nylon) PA (GR) PS	ABS PP Nylon PC	PLA PA Composite Material Rubber-like	Stainless Steel Aluminium Titanium Cobalt chrome	Stainless Steel Tool steel Aluminium Titanium Cobalt chrome	Titanium Cobalt chrome	Tool steel	Tool steel (inexpensive)

2 APPLICATION OF AM IN INDUSTRIAL SECTORS

AM is rapidly spread in many industries while the leading application sectors in the global economic market are aerospace and military, automotive, healthcare and consumer goods industries as well as construction and building, pharmaceutical and food industries. (Rodrigo, Rita, 2020). AM values differ from one industry to another according to business requirements. For example, in the aerospace industry the light weight benefit is very important otherwise in industrial and manufacturing need the production without production tooling. Figure 12 provide technology road map destination in industrial sectors.

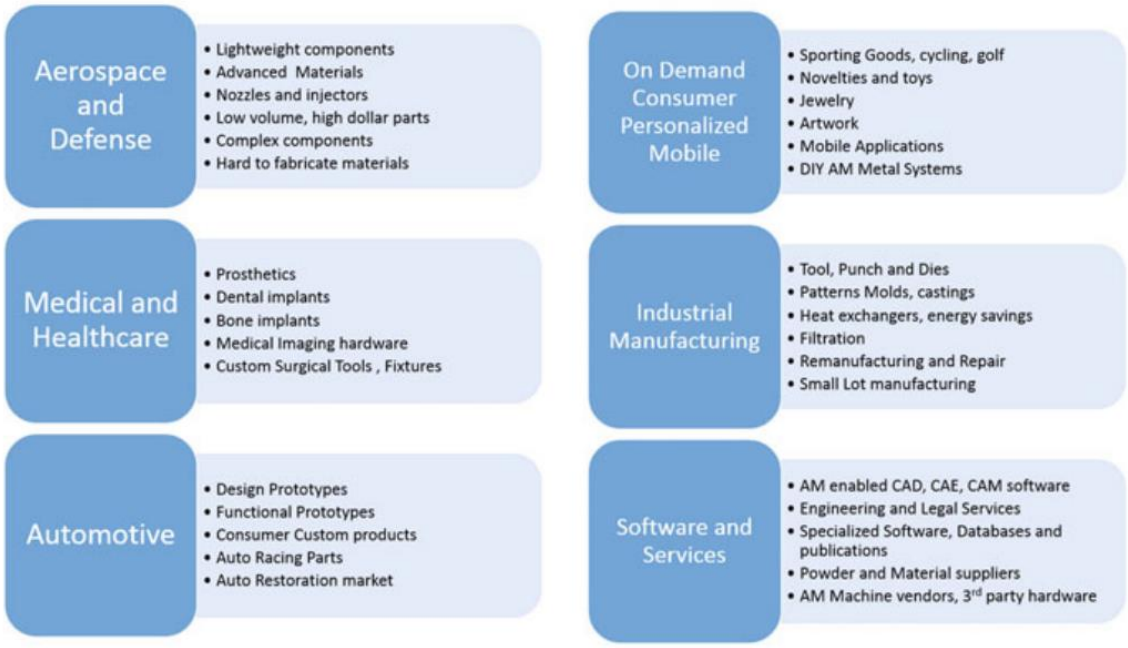

Figure 12 Manufacturing application and market destination (Milewski, 2017)

From industrial point of view, AM mainly used in two purposes: New Product Development NPD and production. AM is used in NPD to produce physical parts for the new ideas or designs for market study, test and product validation before market launch. The development process expenses are significantly decreased with AM. AM become common production tool in different sectors. It solves many problems related to the part function and product performance, but still for small quantities or customized products.

2.1 Aerospace

Aerospace in the first industry used AM in production. 78% of aerospace companies use AM (Karevska et al. 2019). AM affects the aerospace industry such as performing complex geometries for reducing the weight and increasing the part strength. Produce parts using metal cutting methods waste material and cost (Niaki, Nonino, 2017). AM has been used to produce

structural parts, non-structural parts, and low volume replacement parts such as thrust reverser doors, landing gears, and fuel injection nozzles. (Wahlström, Sahlström, 2016).

Design Flexibility and freedom aimed to reduce fuel consumption. Reduce production time (1000 Pcs. In Airbus A350 XWB) Reduce material waste during manufacturing. Nickel alloy Jetliner (Airbus) Figure 13 shows Stiffer structure with fewer pieces [48 Pcs. Into one] reduces weight (35%) (Airbus Aluminium structure bracket for telecommunications) (Wahlström, Sahlström, 2016). Weight could be reduced, and structural safety margins increased. Injector, combustion chamber and expansion nozzle as in Figure 14 combine one part instead of five – European Space Agency ESA.

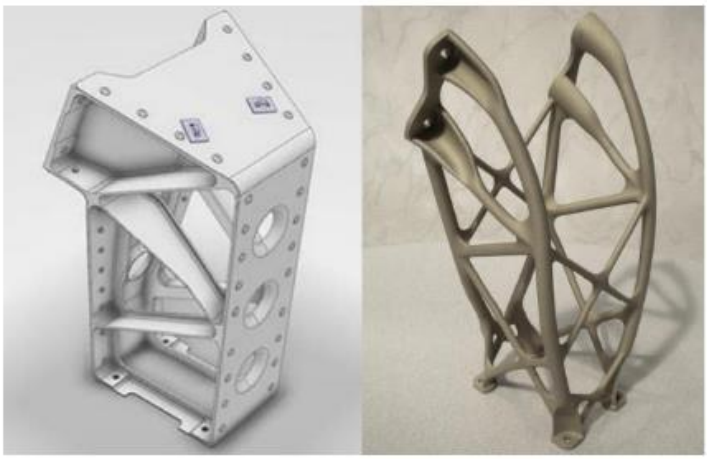

Figure 13 Stiffer structure with fewer pieces (Wahlström, Sahlström, 2016).

Figure 14 Injector, combustion chamber and nozzle (European Space Agency, ESA)

The optimization and the better utilization of material and function, which in turn contributed to a considerable reduction of fuel consumption while also gaining a higher thrust and five times the durability (fuel nozzle – GE) in Figure 15 (Milewski, 2017). Honeywell company produced inlet booster in one piece without welding as original part. The part and cross section of the inside channels which describe the complexity of design as shown in Figure 16 (Godfret, 2015).

Figure 15 Fuel Nozzle – GE (Milewski, 2017).

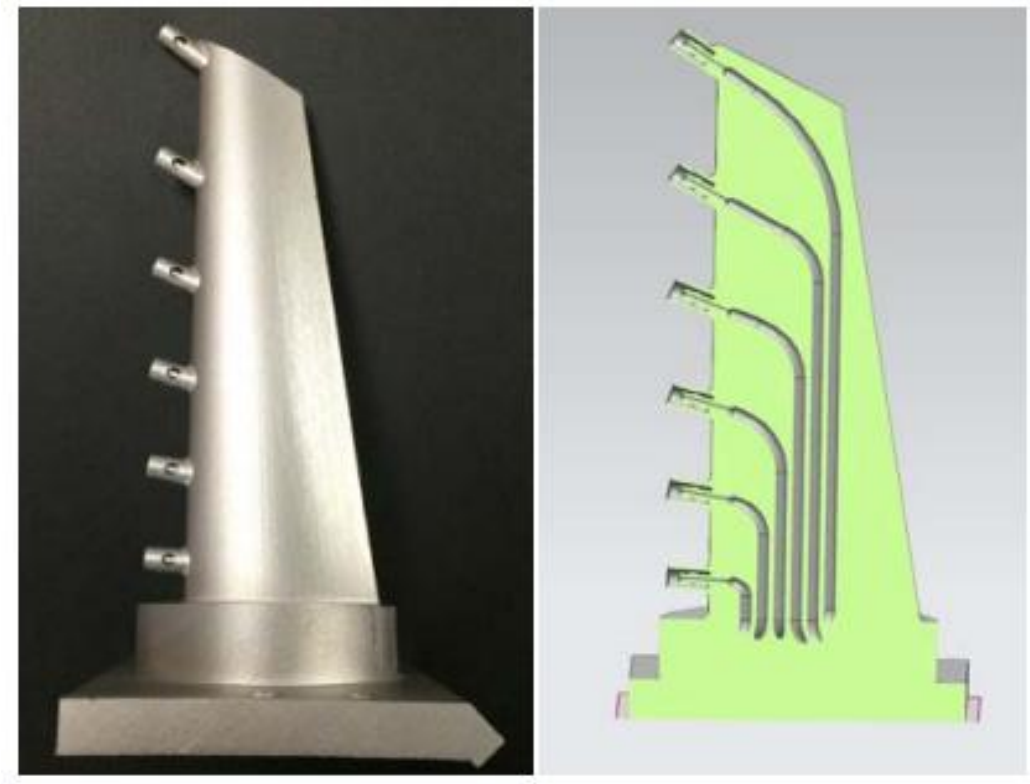

Figure 16 Inlet Booster in one piece without welding – Honeywell. (Godfrey, 2015)

2.2 AUTOMOTIVE INDUSTRY

AM is used in small volumes of production of luxury cars, especially for aesthetic parts and customized parts for antique cars. Replace a metal part with other printed lightweight as well as more complex designs. Produce complex geometry parts and production tooling.

Small quantities of structural and functional components (e.g., engine exhausts, driveshafts, gearbox components, and braking system for luxury) low volume vehicles (e.g., functional components for racing vehicles) low volume, (e.g., custom run speedometer housings, shrouds, and fairings for motorcycles) (Niaki, Nonino, 2017). Use AM in jigs and fixtures (Wahlström, Sahlström, 2016). Hand-held tools for mounting rear trunk lid badges assembly line. The benefits are cost reduction, less lead time, and design freedom.

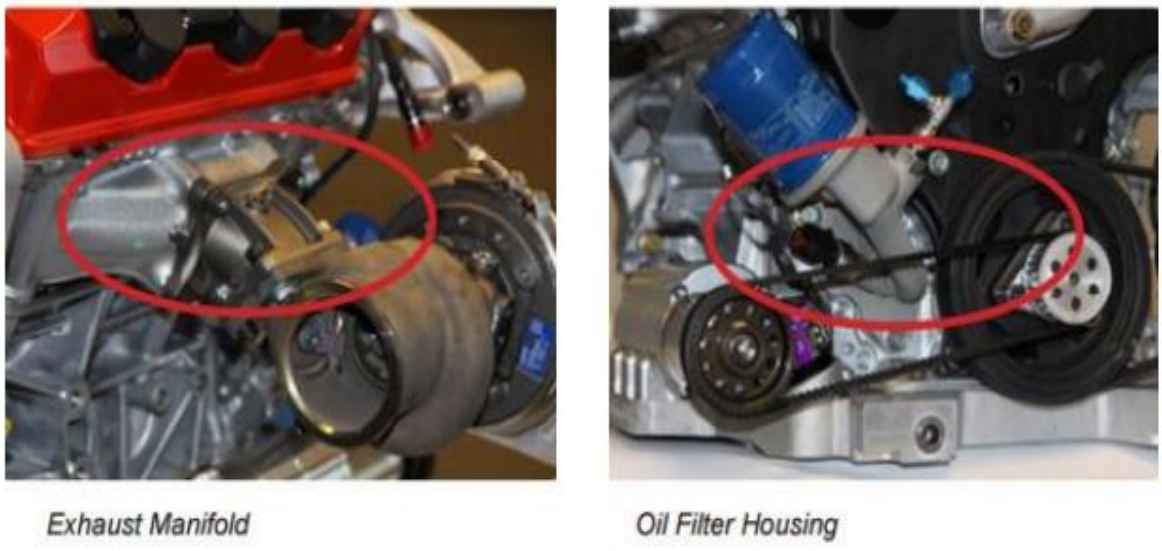

Figure 17 Producing the master pattern for investment casting – Honda (Niaki, Nonino, 2017)

Figure 18 Build platform for hinge bracket for – BMW i8 (Quinlan et al., 2020)

Produce the master pattern using injection wax tools for fabrication the investment casting for Honda as shown in Figure 17 (Niaki, Nonino, 2017). Figure 18 shows the build platform for hinge bracket for BMW i8 (Quinlan et al., 2020). Figure 19 shows the Aluminium water pump wheel instead of plastic in a race car which is an optimized design for hydrodynamics. 500 pieces was used for 5 years without failures in BMW Z4-GT3 (Quinlan et al., 2020). Figure 20 illustrate the stainless-steel turbo housing produced by Koenigsegg. It Save money and time with AM and no need for tooling. Avoid assembly and fitting issues for the moving parts (Wahlström and Sahlström, 2016).

Figure 19 Aluminium water pump wheel – BMW Z4-GT3 (Quinlan *et al.*, 2020)

Figure 20 Stainless steel turbo housing (Wahlström and Sahlström, 2016)

2.3 MEDICAL AND HEALTHCARE INDUSTRY

AM is widely used in the healthcare sector due to atomized shape and functionality and simple and Fast customized, optimized, modified, and produced, sometimes during the surgery. Fabrication of custom-made prostheses and implants medical devices, biological chips, tissue scaffolds, living constructs, drug-screening models, and surgical planning and training apparatus (Niaki, Nonino, 2017). Figure 21 shows metal dental hardware produced by AM for crowns and bridges (Milewski, 2017)

Figure 21 Dental crowns and bridges (Milewski, 2017)

The main applications in the healthcare sector: (Giannatsis, Dedoussis, 2009)

- Bio modelling; produce a part of the human anatomy or structure for surgeries.
- Customized design and fabrication of prosthetic operations
- Fabrication of porous implants and tissue engineering
- Dental applications and the hearing aid parts.

2.4 CONSUMER GOODS

AM increase the design flexibility for consumer goods without the need for production tooling and low material waste during the machining. For example, toys, figurines, furniture, office accessories, musical instruments, art, jeweller, museum displays, and fashion products (Niaki, Nonino, 2017). Figure 22 shows Titanium bike frame as belt on machine platform and the assembled bike with other components for final product. (Milewski, 2017).

Figure 22 Titanium bike frame as belt and as assembled (Milewski, 2017)

AM is used in production tooling's such as plastic injection and thermoforming molds. It reduces the time to market. It is important to use special material suitable for high pressure and temperature such as a tool insert from beryllium copper with modified water-cooling channels. However, it is not durable as traditional plastic and rubber molds. Reduce injection cycle time by using a modified plastic mound cooling system reduces high cycle time and deformations during the injection. Thermoforming production molds are less expensive and durable molds. Easy to make vacuum holes with a good distribution of vacuum during production. (Wahlström, Sahlström, 2016). Figure 23 illustrate the share of AMT in consumer goods sector.

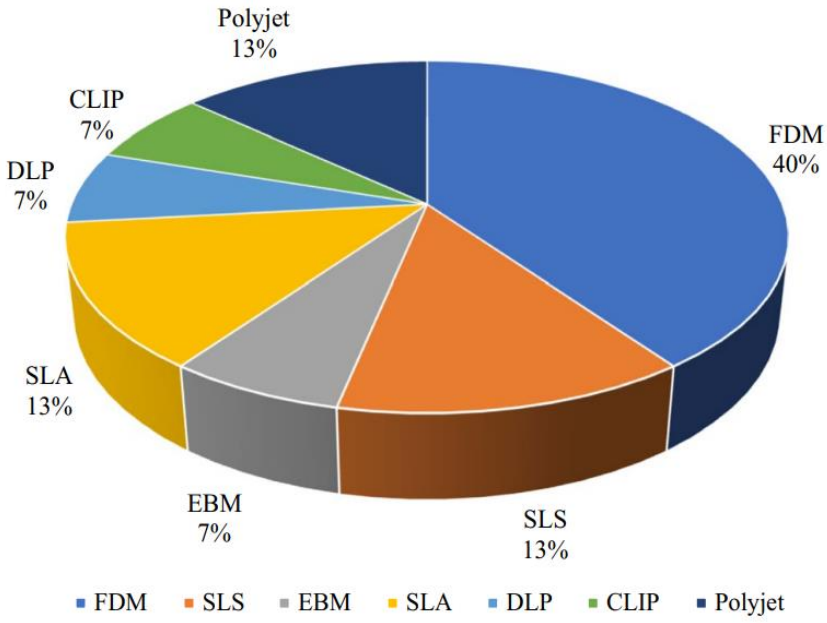

Figure 23 AMT in consumer goods (Damodarn, 2021)

3 AM TECHNOLOGY ECONOMICS

AM Additive manufacturing uses less material during production than CM for similar part design. However, the price of the materials is often more expensive when compared to the original material form for the traditional manufacturing materials, sometimes the material price is nearly ten times, especially the metal material. (Thomas, Gilbert, 2015). It is important to analyse the AM parameters while performing the feasibility of applying.

Additive manufacturing uses less material during production than CM for similar part design. However, the price of the materials is often more expensive when compared to the original material form for the traditional manufacturing materials, sometimes the material price is nearly ten times, especially the metal material. (Thomas, Gilbert, 2015)

This part investigates the cost element and cost drivers. The cost estimation is a kind of prediction about the future so the result of cost must be accurate as possible even if the product is complex to reduce the possibility of uncertainty. The cost estimation is divided into two estimation methods qualitative and quantitative. Each method has two different techniques for predicting the product cost. (Barsing, 2018).

- Qualitative Method: qualitative method may be intuitive by estimating the cost from previous experiences or Analogic estimation is based on relationships and comparison with similar products with known data.
- Quantitative Method: Quantitative Method can be Parametric by using product specifications as a function to estimate the cost such as weight and material or the Analytical which is the breakdown of the product cost to material and manufacturing cost.

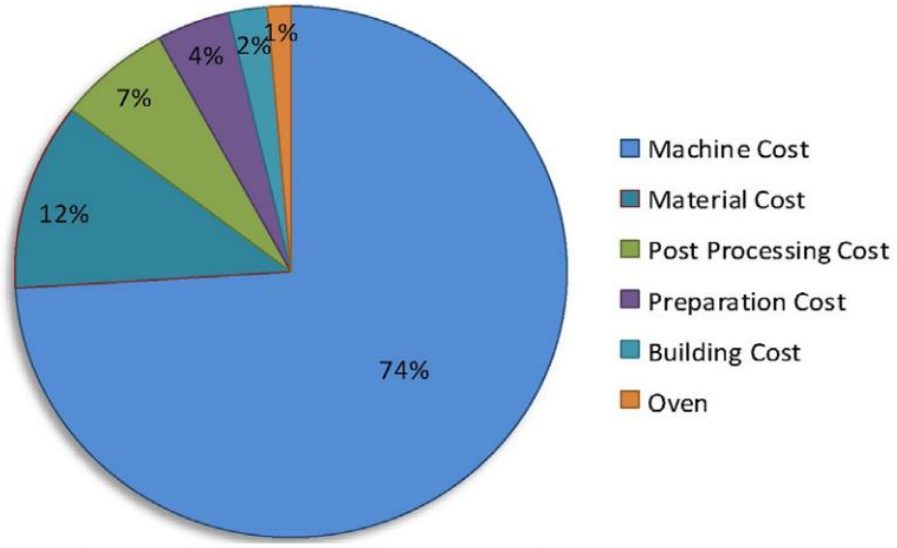

Figure 24 AM cost breakdown (Busachi et al., 2017)

AM machine and material prices is decreasing year-by-year because of increasing of material suppliers and material production patents. Machine price depends on product size and material. Machine of 250×250×250 mm size is from 400K-700K Euro. (Kousa, 2019). AM cost breakdown is illustrated in Figure 24 (Busachi et al., 2017). Material usage efficiency is the ratio of the actual used material. It is very high in AM due to the process principle and the ability to reuse the scrape during the production process. Process labour cost is very low because the machine is fully automatic. Capital cost is varying according to the machine type and technology like conventional machines. Machine utilization is the total operating hours of the machine per year. Power cost: electric power cost and other fuels in some processes such as casting may use gas. Post-processing some manufacturing processes need post-processing like AM. Consumables cutting tools or electrodes in conventional production and AM. Figure 25 shows Forecast of 3D printing cost (Kousa, 2019)

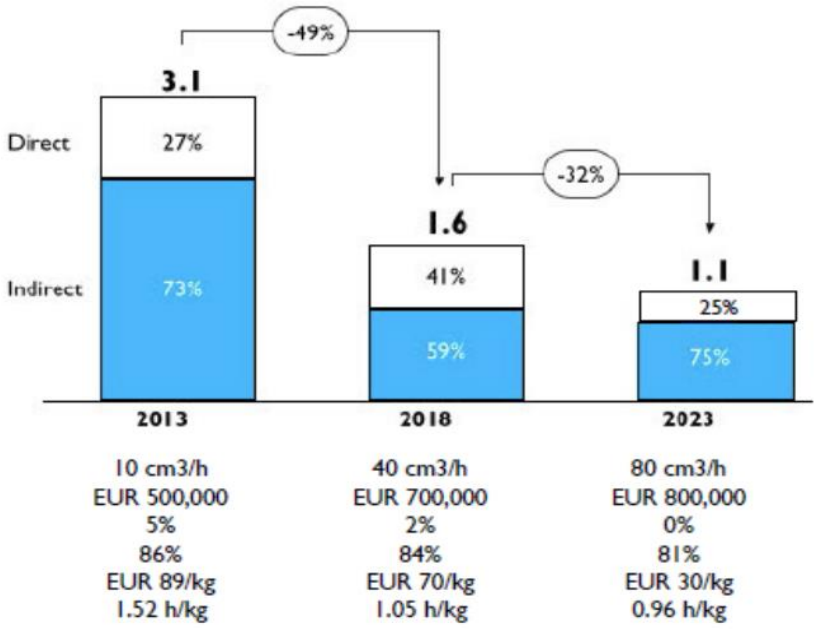

Figure 25 Forecast of 3D printing cost (Kousa, 2019)

3.1 Identify market opportunities

Research and development create and apply new technologies in products for gain new customer segment in current market or target new market for increasing the sales. AMT can introduce a new or modified products with minimum investment. Figure 26 shows the four types of R&D projects. FF, modify familiar technology for familiar market; FN, modify familiar technology for new market; NF, introduce new technology for familiar market; NN, introduce new technology for new market. (Thursby, 2016)

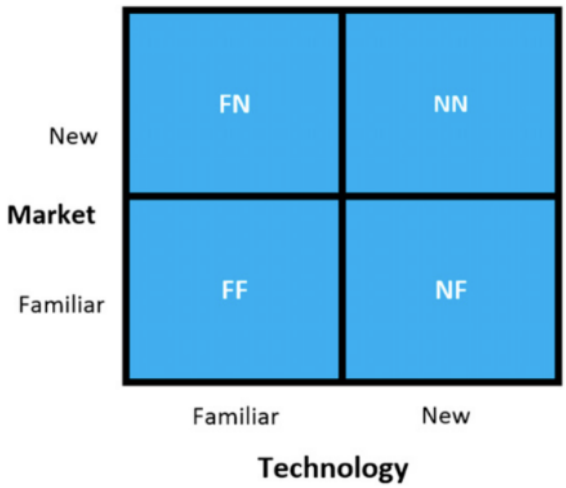

Figure 26 types of R&D Projects (Thursby, 2016)

When we have a deep dive into the home appliances business, we find that Egypt major appliances market increases dramatically last years. The number of users increase from 17 million users in 2020 to 21.3 million in 2021 (Statista, 2022). Egyptian manufacturers import approximately 40% of its raw materials and components of the products, whether in the form of complete product, taking in consideration that Egypt is ranked the first in the Africa in production of home and electrical appliances market (Statista, 2022). The high rate of population growth is considered as an important factor in increasing the demand from 1.2 Mil. product in 2010 to 2.5 Mil. in 2020 with a forecast to reach 2.2 Mil. heads in 2022.

We cannot disregard the fact that local brand names are considered as premium and being sold at a significantly higher price level than the exported or unknown brands.

We capitalize on all the above and target the GAP between imported and local production, with new techniques in production which facilitate the produce OEM products for the exporters who can replace the imported products and buy the product locally with his brand name directly from local manufacturer, and hence reduce the import and investment turnover.

We build 2 models for two case studies, first model is a B2B market (business to business), One of the characteristics of such a market is that payments are made in advance. Therefore, economy of scale plays an important role. Buyers usually buy large number of products and settle payment with his order to get a more favoured price and reduce the order shipping period. AM in production can be recognized as NN project according to figure 26.

The second model is a B2C market (Business to Customer) buy produce special edition products for some occasions or generate a new brand target a new customers' segment, the

selling prices in this model are more stable and are determined by the seller. In addition to quality and after sales services of products provided by the manufacturer are key factors in determining the selling price levels and production stability. It can be recognized as NN.

3.2 Macroeconomy

PEST analysis is an assessment tool measure the major areas of the macroeconomy. The country policies and economical roles of the market and customers. The assessment helps the organization take the right decision. It gives an overview of the market at a period of time. PEST assessment consists of four factors of the market:

Political factors describe the country roles and regulations which may affect the company business.

Economic factors analyse the economic issues which may affect both the company and the customers.

Social and Culture factors containing the demographics and the target customers.

Technological factors which may change around the company change the customer.

3.3 Cost Analysis

The selection and allocation of the cost breakdown is the most important aspect of estimating the cost. Cost breakdown consists of cost elements which are dependent to cost drivers. The cost element such as the material cost depends on the cost drivers such as material price and part weight. I AM the main cost elements are material, preparation, building, and post-processing operations costs. Fig () is visualizing the percentage of share of each cost element in the product's total cost.

Part cost breakdown consists of material cost and manufacturing cost. Manufacturing cost for each method has its costs according to material price and the amount of material consumed for producing the part. Manufacturing cost is a factor of equipment depreciation, power consumption, labour cost, and overheads.(Busachi et al., 2018). Material cost is CM such as metal cutting is the original raw material cost however in AM is the cost of part support material cost. (Allen, 2006).

For cost analysis, it is important to understand that AM saves the amount of operational and manufacturing costs during the product life cycle. AM manufacturing costs may be decreased byte cost of assembly and handling costs by producing integrated and complex

parts. Material cost is low due to less material used. Forming of the part layer-by-layer decreases the material scrape sometimes the need for the support structure. Supply chain savings may be hidden costs such as demand, storage costs and a shorter supply chain by producing the part inside or near the production facility. (Busachi et al., 2017).

Cost can be classified into fixed and variable costs. Fixed cost is the cost do not change with production quantity while variable cost is the cost related to the product quantity. Sales revenue can be defined as the received income because of sales of the product. Net revenue includes all deductions of the sales revenue.

The objective of cost estimation model is to calculate whither the AMT can be a feasible solution in production. The cost analysis is focused on AM part cost including all part related costs. The material consumed and the processing time are the main variables in cost analysis. The machine investment is the major cost fraction of AM part, but the energy cost is the minor fraction (Zamrodah, 2016). Printing single part is slower than multiple part printing (Rickendacher and et al., 2012). As the machine cost is contributing in the part manufacturing cost So to decrease the part production time will decrease the part cost(Mingulia, 2009). More importance as discussed before, the part orientation has two effects on the part production time. First, the required support structure material and its building time. Second, the number of parts on the printing platform in a single printing cycle. It minimizes the machine idle time for the printing head travel during printing and wasted time for removing the produced parts (Pham, Wang, 2000).

In order to calculating the effect of AM production utilization with single and multiple part production for each part, first run should be performed for single product, then the maximum number of parts suitable for the machine are produced. By comparing the cycle time for both cycles we can find the utilization effect of the machine. The saving due to part utilization can be reach 85% of the part cost. (Piili et al., 2015)

Cost can be classified into fixed and variable costs. Fixed cost is the cost do not change with production quantity while variable cost is the cost related to the product quantity. Sales revenue can be defined as the received income because of sales of the product. Net revenue includes all deductions of the sales revenue(Minguella-Canela et al., 2018).

$$\text{Part Total Cost} = \text{Manufacturing Cost} + \text{Material Cost} + \text{labour cost} + \text{Overheads}$$

$$\text{Material Cost} = (\text{Part} + \text{Support total Weight}) \times \text{Material Price}$$

$$\text{Manufacturing Cost} = \text{Total Time} \times \text{Price per unit time}$$

3.4 Breakeven Analysis

Breakeven point refers to the quantity when the company does not make a profit or loss. It can be calculated as the equilibrium point for both the total revenue and total cost. it used to determine the number of products needed to cover the total costs. It is very important indication to know the minimum quantity must be produced to cover all costs. Figure 27 shows break even and the profitability zone for AM.

Break-Even-Point quantity calculation CM Cost = AM Cost

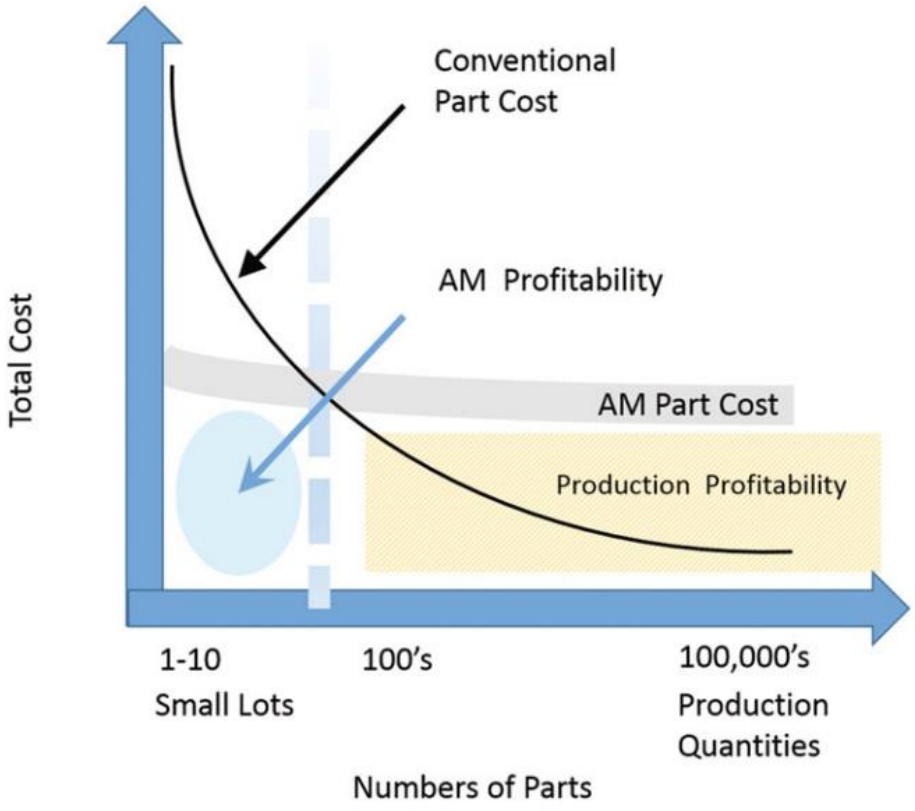

Figure 27 Break even analysis (Milewski, 2017)

3.5 Time Estimation

Cycle time is an important factor for applying AM in production and a great barrier to using AM. Cycle time is the parameter for part cost, material selection and production schedule. Day by day, AM technologies become faster however it is not faster yet fast as other CM especially plastic injection and metal forming. The cycle time depends on part geometry and complexity. (Amini, 2014)

Build Time = Part volume / Machine build rate

Part cycle time = Build Time + Finishing Time

3.6 Return on Investment ROI

Enterprise management needs to have an accurate method for calculating the actual cost and time of AM as for CM. Before applying AMT there are no accurate tools for ROI analysis, especially with the technology uncertainty and limited experience. AM production cost and overheads are still not accurate even if the company know the exact CM costs. Accurate information is also needed to assess the options to invest in AM or outsource part production. As a preliminary analysis, the company can get part production price offers from service providers for both AM and CM which will give a market reality regarding AMT relative to CMT. Although the prices will be higher with the amount of profit margin this margin should cover the hidden costs during producing the part internally such as ordering, storing and handling expenses. Vendor technical assessment in addition to performance and quality qualification should be done before the cost analysis. The vendor assessment helps in the standardization of the results. The technical assessment should contain product size range, material range, accuracy, repeatability, surface finish, performance, and service availability.

The cost curve is the best way for showing the difference between the two technologies. AM Cost curves can illustrate the difference between the cost variations between AM and CM. CM have a high setup and tool manufacturing cost. The cost of CM is declined as the parts produced. For example, plastic injection moulds cost and lead-time are high but the more parts produced the lower cost per piece. On the other hand, AM has a lower initial cost and lead time with no investment and fast time-to-revenue. The break-even point is the intersection between the two curves. The lower quantities are better to be produced by AM while the higher amount should be produced by CM during cost reduction.

Uncertainty and Risk Management

Uncertainty is the incomplete knowledge necessary for forecasting the future and lakes to control the results. It can define as “any deviation from unachievable idea of completely deterministic knowledge of the reverent system”. (Barsing, 2018). The uncertainty can divide into two areas of knowledge Epistemic and Aleatory. Epistemic refers to the limitation of human knowledge. Aleatory refers to the lag of information related to the work processes and steps.

In AM Both Epistemic and Aleatory uncertainty is present. Epistemic uncertainty can be reduced by training courses and increasing the learning curve for human resources. Aleatory

uncertainty can be reduced by describing, analysing, and controlling the AM production processes. We can divide the AM processes to

Preparation and Build process: the relationship between part design, material, AM technology and machine model are very important for producing a successful product. Part design such as geometry, design complexity, and surface finish. Material specifications such as material type and wire diameter or powder grain size. The machine operator set up the machine with building process parameters such as speeds and temperatures and other inputs related to the product axis and part position and orientation. One of the biggest problems in AM part is the poor layer bonding between layers.

Clean-up and post-processing: remove the support structure and residual material. The part orientation is very important to reduce the manufacturing time and cost by using a low amount of material for the support structure. The post-processing process is the final stage for the part finishing it depends on the part application purpose. This is a critical process because it removes the outer rough layer of the part and maintains the required part dimensions as the specifications.

3.7 AM Uncertainty

AM Production uncertainty comes from the part quality and production time and cost. The production rate and product cost are important factors for product feasibility. Part quality is important for the part functionality and final product quality uncertainty we should control are the. The production rate depends on machine setup time, production time, and breakdown. Product cost depends on the material and operating costs and production scrape. The production uncertainty can divide into two categories internal and external uncertainty related to the origin of the uncertainty source.

Table 2 AM Uncertainty

External uncertainty	material uncertainty	- Poor material quality - Late delivery time - Delivery with shortage or shipping of wrong orders
Internal uncertainty	machine uncertainty	- Machine overload, breakdown, unexpected setup time - unavailable tools - Rejected products. - High scrape rate
	scrape or rework uncertainty	
	labour uncertainty	- Workforce low performance due to overload or lack of skills - Workforce lag of availability due to holidays or absences

We can divide the AM processes to build process and post-processing. Preparation and Build process, relationship between part design, material, and AM technology and machine model are very important for producing successful product. Part design such as geometry, design complexity, and surface finish. Material specifications such as material type and wire diameter or powder grain size. The machine operator setup the machine with building process parameters such as speeds and temperatures and other inputs related to the product axis and part position and orientation. Post-processing is the Clean-up process to remove the support structure and residual material. The part orientation is very important to reduce the manufacturing time and cost by using of low amount of material for support structure. The post-processing process is the final stage for the part finishing it depends on the part application purpose. This is a critical process because it removes the outer rough layer of the part and maintain the required part dimensions as the specifications.

3.8 Risk Project Analysis RIPRAN

Risk management is the process of controlling and managing the risk threaten the AM implementation project during its life cycle. Risk rate is high in new product development. (Buganová, Šimíčková, 2019). AMT is a new technology and use in new product development so the risk in higher.

RIPRAN method (RIsk PRoject ANalysis) is an empirical project risk analysis methodology. It should be done in all project phases before project implementation. The objective is to identify everything can be a risk. whenever new danger appears, or the situation changes and requires the re-evaluation of a certain risk, it is possible to use the RIPRAN method again also during the monitoring of the project risks. (RIPRAN, 2022)

RIPRAN Analysis Method consists of the following phases

Risk analysis

In this phase, the time schedule for the procedure is drawn up, the necessary documents for the risk analysis are secured, decisions are made on the use of scales, checklists and the risk analysis team are formed.

Risk identification

The inputs for this part of the risk analysis are the description of the project, historical data on past projects, forecasts of possible internal and external influences. The output is a list of threat-scenario pairs. If we are looking for possible consequences for a threat, we answer the

question: What can happen in an unfavourable project? But we can also answer the question: What can be the cause of something unfavourable happening in the project? in this way we look for the causes of the scenario. We must always check that we have assigned all significant scenarios to a certain threat and vice versa.

Quantification of risk

The goal is to evaluate the probability of scenarios, evaluate the level of risk and the amount of damage. The resulting probabilities are calculated by multiplying the probability of the threat and the scenario expressed in decimal numbers in the range 0-1 (for a 50% probability, we calculate the number 0.5). The table can have the following form

Table 3 RIPRAN Analysis Table

Serial number	
Risk Threat	Risk Description
Scenario	Description of the next situation
Probability of Occurrence	Rating 0-1
Impact on the project	Financial evaluation
Risk value	The product of the resulting probability and the risk value
Measure	Description of risk and action may eliminate the risk

Risk response

Based on awareness of the danger, it is necessary to prepare measures that reduce the value of individual risks to an acceptable level. The RIPRAN method lists the so-called type measures to reduce risks: alternative solutions, elimination of the source of threats, protection against the threat, modification of the scenario, reduction of the size of the impact, reduction of the probability of the occurrence of the scenario, mobilization of reserves, transfer, or distribution of risk.

Overall risk assessment

The goal is to evaluate the analysed risks of the project. We will carry out a risk acceptability check. If the magnitude of the risk remains too high despite the proposed measures, it is necessary to consider stopping the project or escalating the problem to a higher level of management. It is also important to complete the overall documentation of the analysis procedure in the final report.

4 FACTORS AFFECTING AM APPLICATION IN PRODUCTION

AM add great value to the and eliminate CM disadvantages. However, there are barriers to application such as cost, cycle time and the need for special actions for implementations produced. AM Technology Benefits:

4.1 Reduce Time-to-Market

AM Reduce the time to market for a product by reducing new product design NPD lead time. Quick response to design changes for current products is a great benefit. The design change may be due to quality issues, market changes, or customer needs for a response. Producing a complex part with conventional production can be very slow or impossible is some cases. Figure 28 illustrate a copper complex heat exchanger for motorcycle engine (Milewski, 2017)

Figure 28 copper complex heat exchanger for motorcycle engine (Milewski, 2017)

4.2 Minimize Material Consumption

Lightweight part with the same strength and function is important, especially in the aerospace and automotive industries. The part design efficiency is measured by calculating the strength-to-weight ratio. Decrease the part weight leads to fast production and less part cost due to the reduction of the material consumption and scrap percentage. AMT is a suitable technology for producing lightweight parts. For example, the Production of aircraft titanium gear parts using metal cutting methods from titanium block waste material and cost (Campbell et al., 2011). There are two different methodologies to Produce lightweight part:

An internal lattice structure is a hollow part that contains a support structure in the internal layers of the part such as the honey-comp structure. Figure 29 shows examples of the hollow lightweight parts.

Figure 29 hollow lightweight parts (All3DP, 2022)

Generative design technology is a new 3D modelling method for creating optimized design parts by computer software. The designer gives the load and constraints to the software to offer designs that meet design requirements with the least material. The computer simulates and analyses this part with the given data and removes all unused material from the part geometry and gives a part with relatively low material and weight (Milewski, 2017). Figure 30 illustrates the part stress analysis model after modification (AUTODESK, 2022). The software also gives alternative designs for the part as shown in Figure 31 (PTC, 2020).

Figure 30 Generative design alternative (AUTODESK, 2022) (Siemens, 2022)

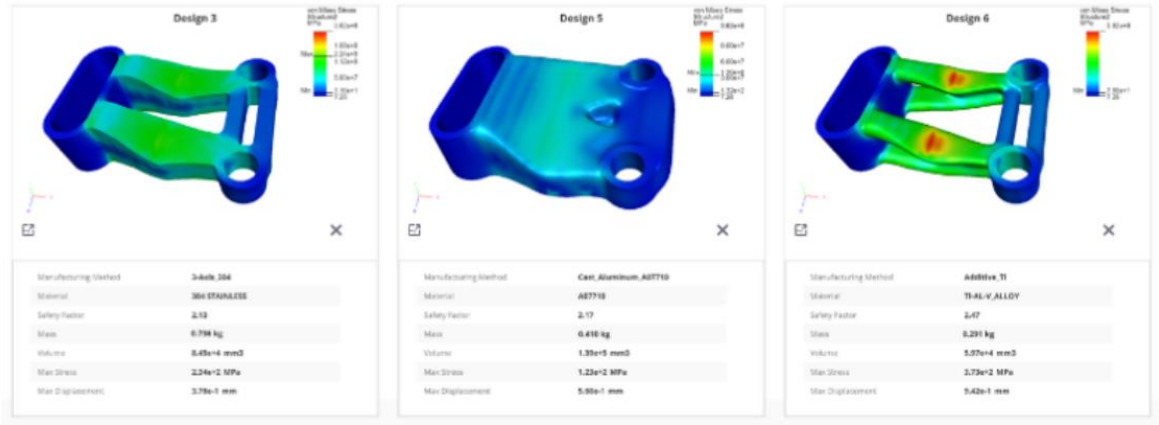

Figure 31 Generative design simulation (PTC, 2020)

4.3 Quality Enhancement with Complex Geometry

AM gives a new opportunity for Integrated and complex parts with optimized designs. AM is the cheapest fastest production technology for producing Complex geometries such as merging and producing a complete assembly in one part or adding internal fuel, cooling, or lubrication in complex ways inside the part material (Wahlström, Sahlström, 2016). Figure 32 shows the relationship between the product complexity versus manufacturing cost for both AM and CM.

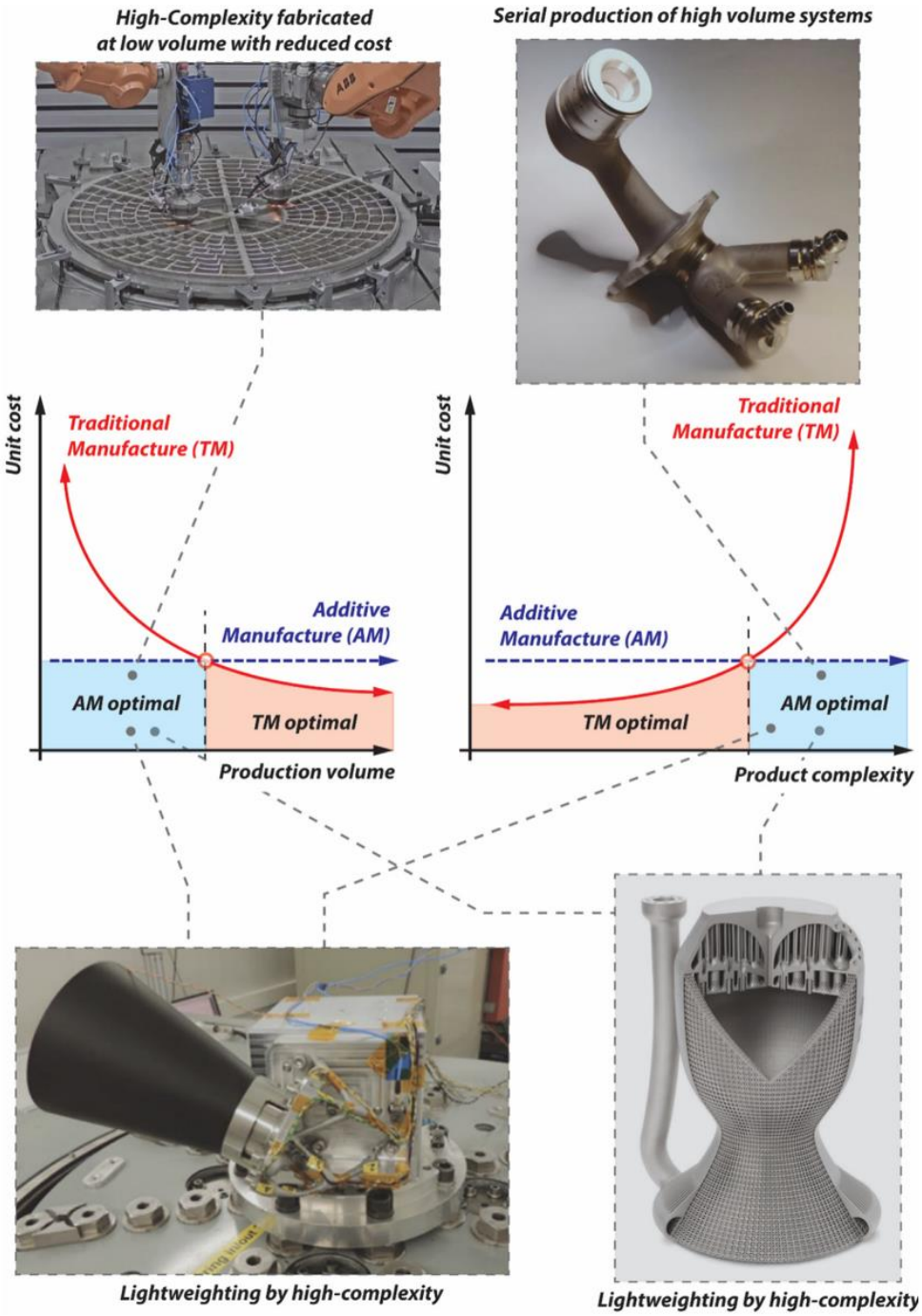

Figure 32 Part complexity effect on part cost (Allen, 2006) (Blakey, Milner, 2021)

4.4 Reduce Investment in Production Tooling

The benefit of the use of AM to manufacture production tools is to reduce tooling lead time and cost. The largest concern is the decreased die rigidity and abrasive wear. AMT can be used for mould cavity and metal forming dies. For example, the finish company Salcomp use AM for producing the plastic moulds cavities with the internal cooling complex path it reduces the injection cycle time from14 to 8 seconds per part which allows the production of more than sixty-five thousand monthly. GE products fuel aircraft engines to merge the part from twenty parts into one single part precisely to realize the function by using AM (Niaki, Nonino, 2017). Figure (33) shows Production of injection moulding tooling (Mirzababaei, Pasebani, 2019).

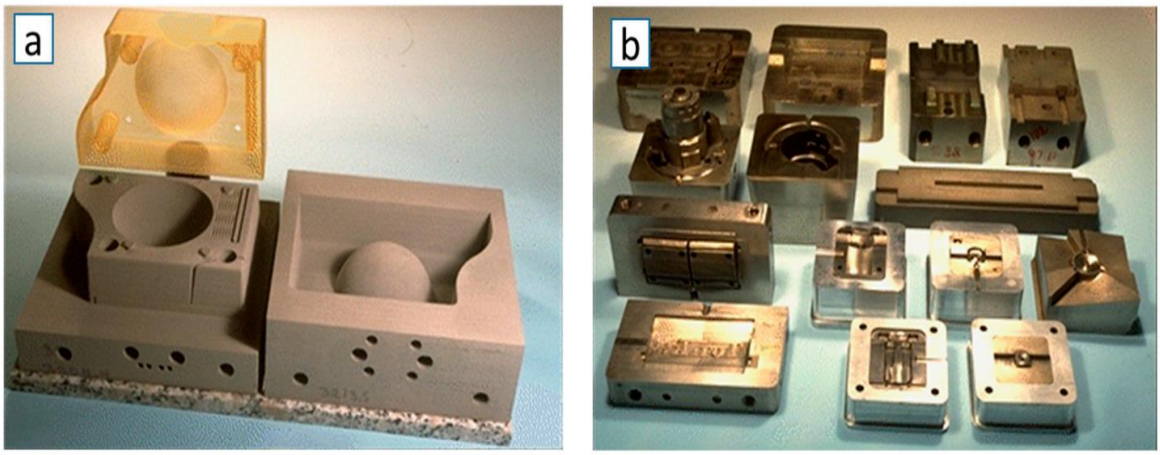

Figure 33 Dies and mould tooling insert (EOS 2018) (Mirzababaei, Pasebani, 2019)

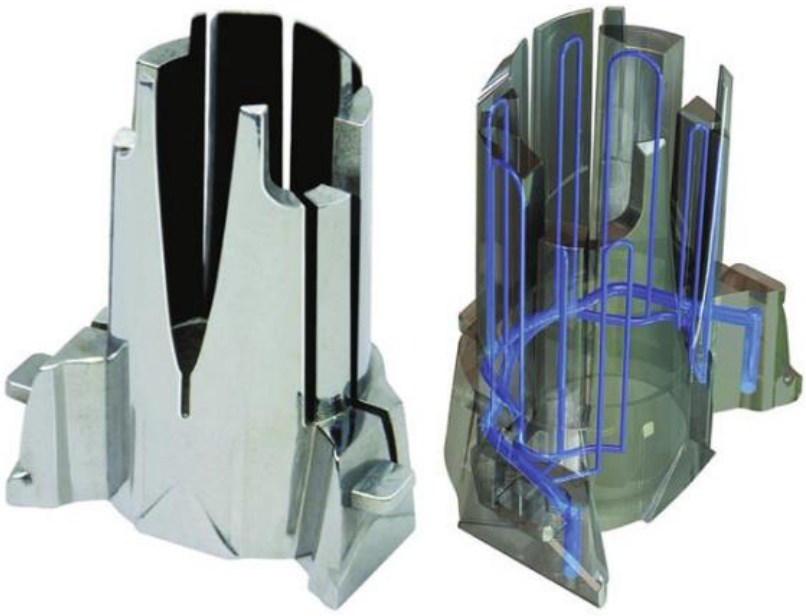

Figure 34 cooling channels inside the mould part (Milewski, 2017)

4.5 Supply Chain Value-added

AM is a great tool for applying agility manufacturing with Low inventory stock size managing the supply chain Spare parts expenditure mainly increases due to holding many parts safety-inventory of the frequently needed components and expenses of shipping costs and time for moving the parts; usually for slow wearing out and unpredictable parts.

4.6 AM Value for Business and Operations Strategies

AM gives great value to business and operations strategies and drives the firm's creativity and competitiveness. AM is a Driver of Business Competitiveness. Each industry has its competitors which may be in design, production, or processing. For example, weight and material saving are the most important factors in aerospace and automotive, while functionalities and substances integration are for the healthcare industry and customization degree is the main required factor in consumer goods. Factors in determining business competitiveness are Fast response to business opportunities and Manufacturing flexibility, while low operational costs are an advantage. The business strategy guides the operations strategy (Niaki, Nonino, 2017).

The operations strategy concerns the production process of quality, cost, time, and flexibility. It differs from one company to another due to choosing different performance objectives, because affects the long-term operation and resources development. For example, some companies incorporate sustainability, so they consider energy consumption, efficient use of resources and societal aspects.

4.7 Manufacturing Paradigms Flexibility

The current manufacturing paradigms can be changed by the AM implementation in production. According to (Niaki, Nonino, 2017). Figure 1.7 illustrates a comparison between the manufacturing paradigms which can be classified into four typologies in Figure 35 (Danfang, Chen, Heyer et al., 2015):

Craft manufacturing: craft skills of some experts for producing small volumes of products in their local communities for a few numbers of customers.

Mass manufacturing: standard products with large production volumes based on specific designs.

Mass customization: mass customization is like mass production, but customers can choose a special feature or design for their product. AMT as a production method will add the feature of customer direct choice of product. The potential is to produce mass production for unique items according to special inputs (Jordan, 2019).

Direct digital manufacturing: Direct digital manufacturing method is the customization of the product design with the consumer's ability to produce the product locally. It also gives a business opportunity for entrepreneurship.

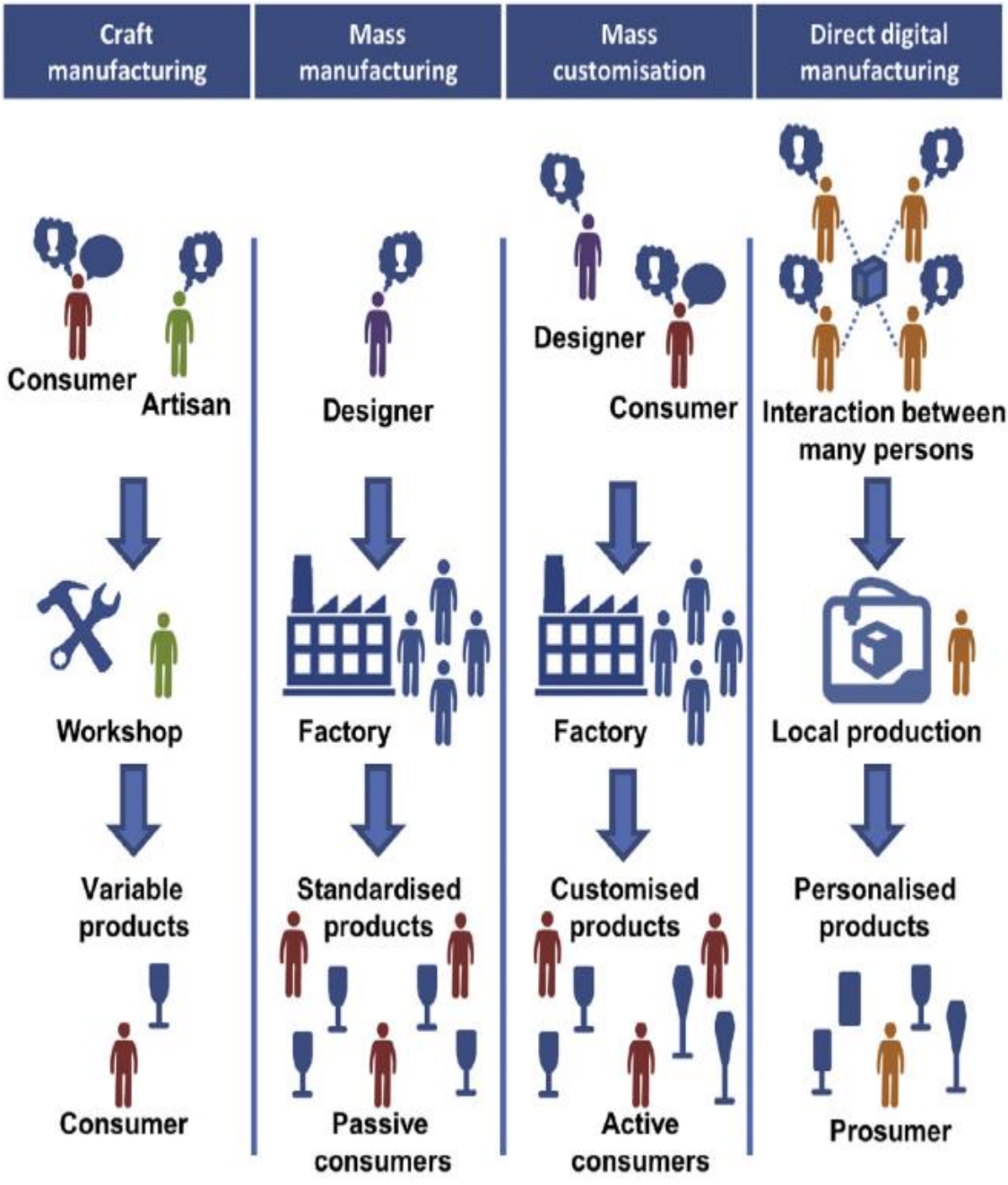

Figure 35 Manufacturing paradigms and main actors (Danfang, Chen, Heyer et al., 2015)

5 AM IMPLEMENTATION IN PRODUCTION

Applying AM in production in an organization is not just a replacement for CM methodology. It is a new technology with a great challenge need to concentrate on making new functional and organizational roles. The implementation process is divided into the organizational framework for implementation which deals with the organizational activities and roles and product factors which is dealing with technical analysis and feasibility of production of the part. AM cannot replace the current part production technology easily. Organizations should apply this new technology in which AM feasible can provide a value add. It is important to know the advantages and disadvantages during selection (Thomas and Gilbert, 2015).

5.1 Organization Conceptual Framework

Conceptual framework factors for implementing AM in production are strategic factors, organizational factors, operational factors, technological factors, and supply chain factors as figure 36 (Handal 2017) (Mellor, 2014).

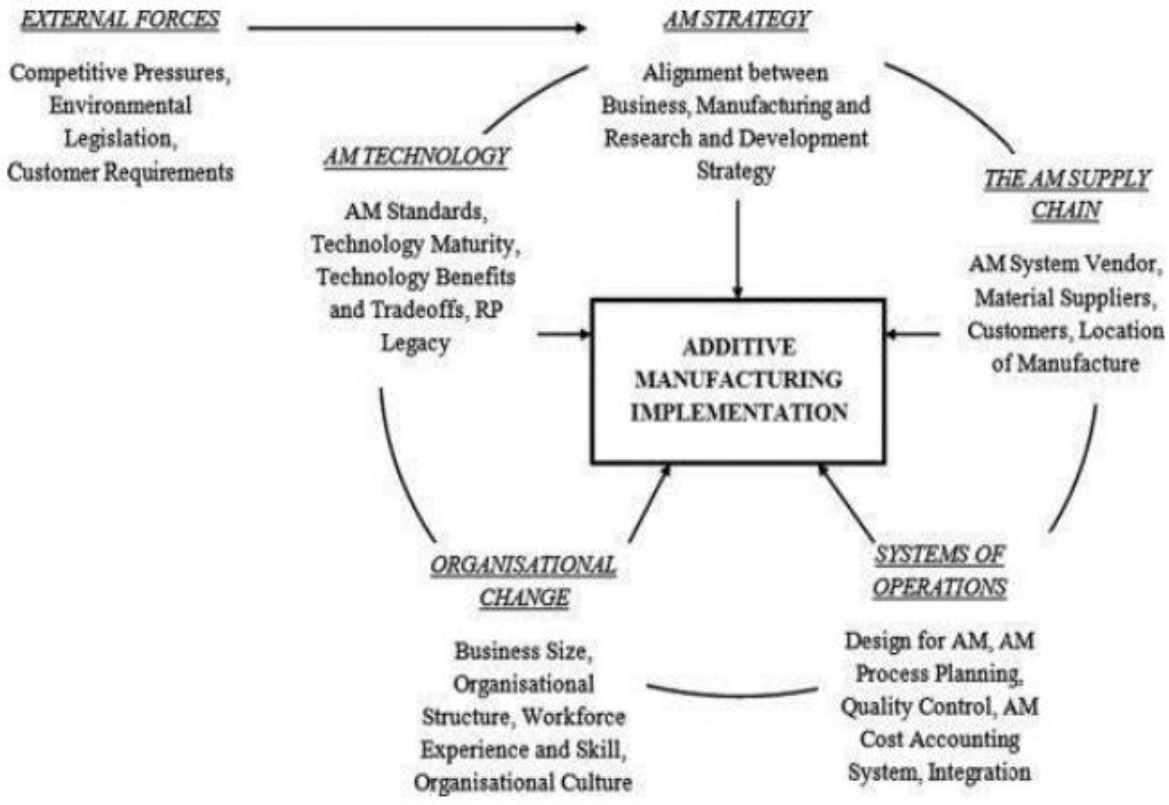

Figure 36 Framework of implementation of AM (Handal, 2017)

5.1.1 Strategic factors

Strategic Factors while implementing AM need alignment between business, manufacturing, and technology strategies. It is based on current firm capabilities and resources and links with building new investments and business opportunities.

Business strategy is the long-term action plan for the company to achieve its vision. Companies start with current processes to adapt and apply the new technology. Furthermore, product design, use price, quality, and delivery services as factors to drive the company for long term competitive advantages. Business strategy process contains activities (Khajavi, Partanen, Holmström, 2014). The company must identify its main business and then Identify the customer needs or opportunities for applying AM with company experience in the field. Create the business model for the new technology. establish markets for the new products. Market demand.

The manufacturing strategy should support the business strategy objectives. It is the capability of production and volume which comes from the relations between the type of product (standard or customized product), product range, customer order size, and rate of change of the product.

manufacturing strategy process contains activities should applied in company. Prepare a study of the first step of AM investment as the technology entry point. Provide the data related to productivity and improvements. prepare the parts required for production volume. (Khajavi, Partanen, Holmström, 2014).

Technology strategy is the technology goal which we need to build from the current technical knowledge of the business and the link technical capabilities and our target. Technology strategy is the investment in new machines and training plan for the organization to meet our target. There is high uncertainty with the new technology, and it is hard for predicting the profitability and feasibility of the new idea. Strategies may be push strategy or pull strategy. push strategy reflects the technology-based arguments while the pull strategy is related to market needs. Design strategy process contains the following activities (Khajavi, Partanen, Holmström, 2014). Hire skilled designers start for the part redesign. Need large investment and training of employees and AM machines selection were used first for a prototype in the validation phase. The risk is very high because the AM is a new technology.

5.1.2 Organizational factors

The interrelationship between the product and the organizational factors such as organization size, organizational structure, workforce training, and organizational culture is a great indicator of AM implementation success. For example, the organisational factors affect the decision for tasks and resistance to technological changes while adopting AM. The sponsor is the executive sponsor who can support the project. stakeholders from the current operation and design team and the new team. The current teams who work with the original part can know exactly all related performance and quality parameters. (Handal, 2017).

5.1.3 Operational factors

the organization should have a modern design system and CAD software. changes in a firm will influence both operational and organizational structure. Operational factors such as integration of new technology, product design operation, process planning and control, and cost calculation method. Human resources capabilities of engineering and design combined with digitalization. The skills of computer software, material science, operations, manufacturing, and engineering are required. Assign AM department activities is important for steering the project. The responsibilities of AM department should cover the following tasks. Manage projects and implementation of AM inside the organization. Support all manufacturing operations and product development for AM. Data collection for production capabilities, activities, and volumes. Identify the parts for starting production with AM. Finally prepare the production process sequences. (Handal, 2017)

5.1.4 AM Technological factors

there are different criteria for technology selection and evaluation is important so it. Selection, Justification, Benefits, trade-offs, Technology maturity, Rapid prototype legacy.

5.1.5 AM Supply chain factors

The implementation process lies at the intersection between machine and material vendors and the customer’s channels.

5.2 Technology Framework

Applying AM is not just looking at a part and deciding which AM method is suitable for it. it is the study and analysis of product parts and subassemblies then redesign for AM. Part Technical Characteristics differentiate the product from each other and support the decision

for selecting a specific part. (Aliakbari, 2012). Identification of parts for study: start with a manufacturing survey to identify specific parts that may be produced with AM and the different criteria to fit the technology. Clarify how it fits a kind of AM advantage. Check if the part is fitting those criteria and the needs to be identified.

The selection criteria are mainly technical and economic which are linked together. The technical aspect comes from the manufacturing limitations of AM technology. AM can produce metal alloys, non-metals, or composite materials without active function such as electric and electronic components while the electronic and electric components have higher value-added during the production. The part economic aspect and cost-saving have a great incentive for pushing the project. The part cost depends on material, design, manufacturing cost and time, storage, etc.

This aims to give systematic procedures for the organizations which need to apply AM in production and selection criteria for selecting the part suitable for production with AM. First, we should know the alternative equipment and material available. Use AM for adding values for the product. A list of parts for assessment should be developed by the product stakeholders. The assessment should cover design, manufacturing, economic, and supply chain aspects. Finally, rank the parts according to the assessment results.

The value to be added or the problem we need to solve and part function and end-user requirements. Then start redesign the part for AM adding value and select a suitable part for implementing AM in producing it for production. Select the type of machine or technology for this product and Material selection.

key phrases in the implementation of AM systems

developing the business case: define a specific area for profit by new value add or cost benefits.

the organizational action plan: mapping out how AM change the production process.

the operational action plan: Build a support structure for taking advantage of AM and reduce the barriers to applying.

the AM supply chain: Deciding whether to invest in machines or outsource (Buy / make decisions).

II. ANALYSIS

6 CURRENT STATE OF USING AM IN INDUSTRIAL COMPANIES

Nowadays, the ease of use and shared open sources designs help in spreading of the technology in companies, universities, and individuals as well. It is important to identify the general trends of AM in government programs, universities, and industry. Government programs provides vision of advanced manufacturing such as AM. As an example, The European Space Agency ESA launch projects for digital fabrication focused on developing AM aero engines components. Governments, software companies and universities launch an integrated databases for downloading and sharing some designs for functional parts and components to help industry development. Designers get information and designs from database as a design input to prepare and send it to production machine (Milewski, 2017). AM benefits are the core for supporting the new technology by governments in near future. The flexibility and simplicity of manufacturing in addition to economic benefits is the main reason for empowering and support companies to use it. Technology improvement with speed, material, and accuracy push it to use in production not only the prototyping (Gibson, Rosen, Stucker, 2015). According to John Jordan, AM machines usage according to machines manufacturers are 33.8% for producing functional parts, 7.1% aesthetic parts and models, 7.3% other visual aids,16% for part prototypes, 7.4% prototype tooling, 7.4% production tooling, 10.7% in research and education, 8.3% for casting pattern (Jordan, 2019). Figure 37 shows the level of expertise in 3d printing by industrial sector.

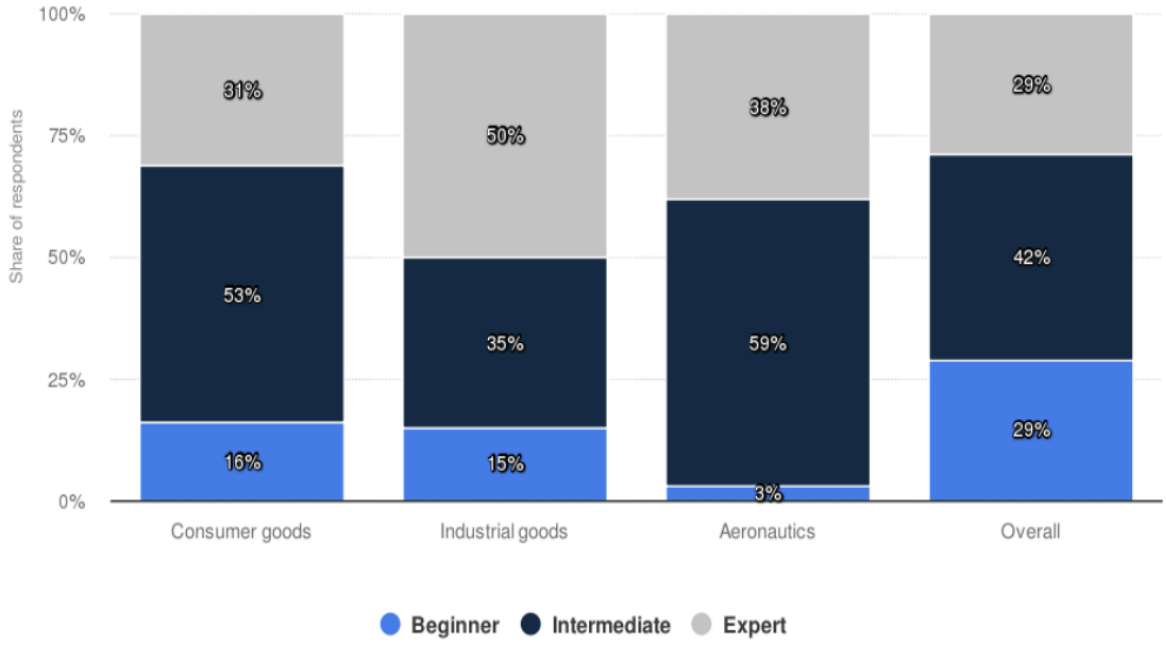

Figure 37 Level of expertise in 3d printing by industrial sector (Statista, 2022).

The main profitable areas are in industry are in prototyping, customized and limited quantity parts, high complexity parts, and remotely production for spare parts. the technology spread quickly however the barrier are often comes from organizational issues, process workflows and the cost estimation difficulties. The accurate cost estimation difficulties such as the changeover cost for changing the model of the product, assembly cost saving by part consolidation, minimize the investment needed for production tooling, reduce the storage of the spare parts, and savings due to remap the product supply chain (Jordan, 2019). In production, AM can be used in many applications such as mass production moulds, precise jigs, and tools. Rebuild machine parts for maintenance use is also a great value added to the industrial environment. It eliminates the stoppage of machines and waiting for weeks to prepare the part. In addition to production of limited quantity of parts for final product So the break-even analysis is an important tool for calculating the critical quantity which helps to know the limit of feasibility of apply AM in final product. AM sales revenue distribution is shown in figure 38.

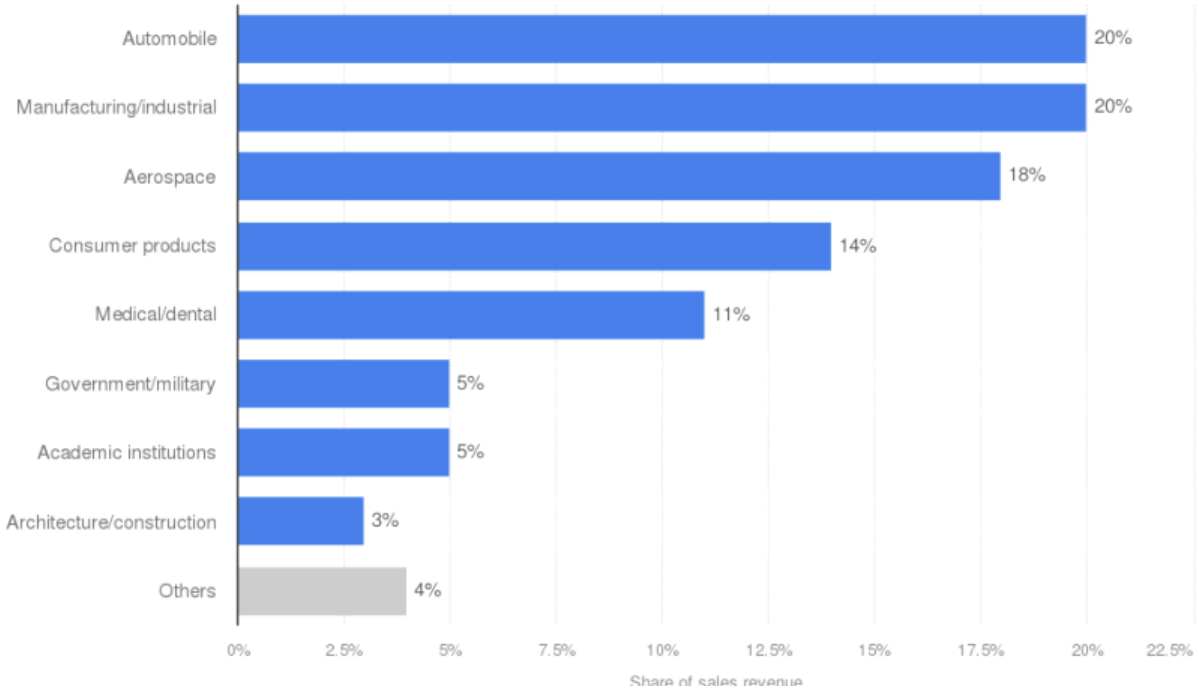

Figure 38 AM sales revenue distribution in 2019 (Statista, 2022)

AM technology jumps to consumer goods especially home appliances field. Companies usually apply the new technologies and innovations which can help in high volume mass production. the application and investment were for prototyping of components for acceleration the new product development process.

6.1 Usage of AM in Home Appliances

Home appliances consists of many components which are manufactured and produced inside the factory or may be outsourcing. Factories usually have the production assembly line and two main production areas which feeding the assembly line with main large parts. First area produces sheet metal cabinet and painting. The second area is plastics area which producing large plastic part. The assembly line produces the final packaged product using the parts from feeding areas and the remaining other parts and components purchased from outsource suppliers. Washing machine manufacturers for example usually produce the sheet metal cabinet, internal stainless-steel drum and plastic drum tub inside the factory. Figure 39 shows the production process of washing machine (Yuan, Zhang, Liu, 2016).

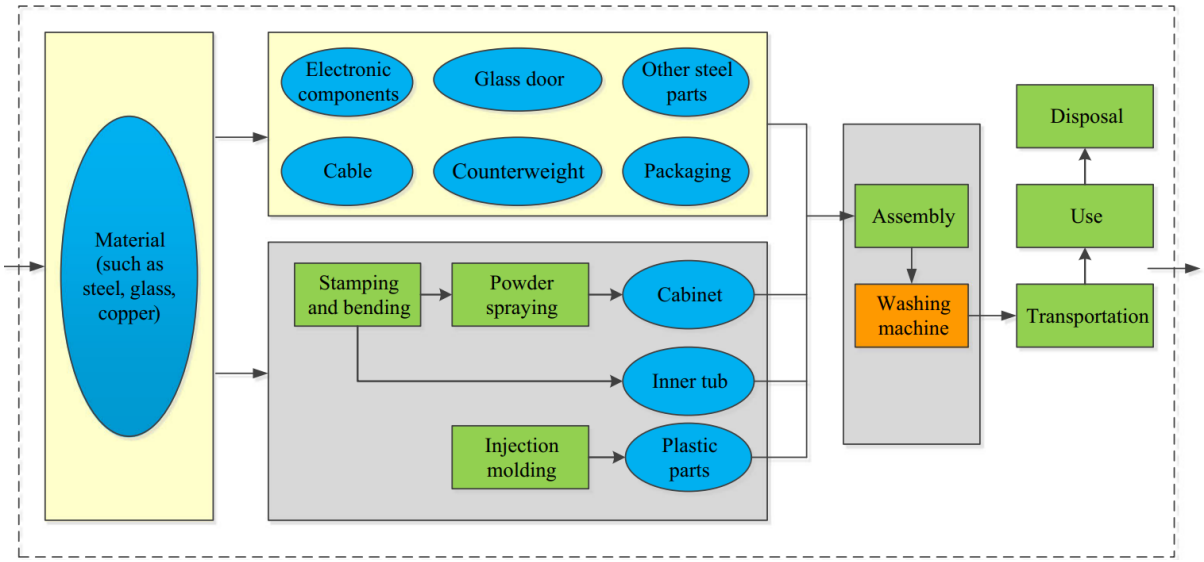

Figure 39 washing machine production processes (Yuan, Zhang, Liu, 2016).

Assembly line stoppage occurs due to quality problems in any part can stop the assembly line and all the production processes. The problem or error should be systematically traced to the main root cause quickly to implementing the required actions to prevent the stoppage time. There are two types of repairs in in-line repairs and off-line repairs. The in-line repair is the more expensive action because it may stop all production processes. The worst case if the root cause analysis result that a problem or cumulative problems which could be solved by modify one or more parts in the product. The modification in one part of the product may take weeks to modify its production tools. The stoppage or delay cost consists of the stoppage time multiplied by the operating cost per unit. The labour cost is the major component of the operational cost. the other fixed and variable costs can be covered. While the production operations should cover the target production plan to meet the sales plan so by operating the assembly line with overtime base, we can cover stoppage cost (Shin, Min, 1995).

6.2 AM Implementation Methodology

This section aims to summarize the overall theoretical part to give systematic procedures for the organizations to apply AM in production and selection criteria for the suitable parts to be produced by AM. Again, AM cannot replace the current part production technology without paying attention organizations, to the technical and economic implementation aspects. The selection criteria mainly use organizational, technical, and economistic aspects and are links between each other. the technicalities are coming from the manufacturing limitations of AM technology. AM can produce metal alloys, non-metals, or composite materials without active function such as electric and electronic components while the electronic and electric components have higher value-added production. Implementation of AM in production: (Khajavi, Partanen, Holmström, 2014) (Thomas, Gilbert, 2015)

6.2.1 Organization Aspect

Prepare the organizational action plan and map out how AM change the production.

Business strategy

- Identify the company's business and operational strategy and manufacturing paradigms.
- Identify the market opportunities and target customers for the new products. Establish the market demand and customers' needs.
- Create a business model. Developing the business case and defining a specific area for profit by new value add or cost benefits.

Manufacturing strategy

- Buy / make decision is important at this moment to decide whether to invest in machines or outsource the service because the AMT risk and uncertainty are high, and it needs large investment in equipment, processes, and training.
- Prepare a study of the first step of AM investment as the technology entry point.
- Provide the productivity and improvement scenarios which AM can be used.

Design Strategy

- Design for AM starts with hiring high skilled designers.
- AM machines are used first for a prototype in the validation phase.

- Assign a cross matrix AM team.(Handal, 2017)

6.2.2 Product Aspect

- Define the target parts list to perform technical analysis and part assessment.
- Estimate the parts production volume.
- Select suitable parts for implementing AM in producing or production. Perform parts technical assessment. Consider the factors affecting the AM cost reduction.
- Part design for AM: select the part suitable for AM from AMT point of view according to the following aspects. Modify the design of the part for AM.
- AM technology selection and material Selection by using Table 1
- Fix cost and time calculation rule to be easy to calculate at the moment we need to apply.

7 USE OF AM IN HOME APPLIANCES OF EGYPT MARKET

The market of the home appliances will be analysed from two phases; the B2B, which involves selling OEM products for traders, and the B2C which involves selling to end consumers. In B2B free market, the price is experiencing fluctuations according to demand and supply. Seasonality also plays a role in increasing or decreasing demand on special products for the end user. When demand is high, prices increase as well, and the power of buyers decreases accordingly. An opposite situation occurs when demand is low and buyers have more available supply, hence bargaining power of supply increases.

One of the characteristics of such a market is that payments are made three months in advance. Therefore, buyers who could buy large order and settle payment on cash have more strength to get a more favoured price. For B2C, the selling prices in this phase are more stable and are determined by the seller. Quality and after sales services of the product are key factors in determining the selling price levels. Additional product brand name would contribute to reducing the bargaining power of buyers. The buyer power comes from the availability of different products in the market. The number of buyers (beneficiaries) is large, and they favour differentiated product in terms of high-quality products, which represents and a point of attractiveness for the business model.

7.1 PEST analysis

Political Analysis:

Home appliances is considered as “mandatory products” for the Egyptian Government as it is a necessity of normal daily use for people. Therefore, Government has always interfered in its market, either directly or indirectly. Direct by produce the product in government owned factories with its own brands and indirect by support the industry.

The pretext on which the government based its dramatic actions was simple and familiar one. They claimed that; the marketing of appliances had been oligopolies a by a few large and powerful manufacturer who were attempting to hold back supplies and decrease the number of importers thereby rake off excess profits. At the same time, however, the floatation of the Egyptian pound in late 2016 and 2022 has caused the prices to escalate significantly. The main reason for floatation is the decrease of USD sources. This has constituted a challenge for the Government.

The availability of such a strategic commodity is viewed vital for internal stability in a country that is recovering from a revolution. Direct interference would be through direct manufacturing products to consumers through government related factories. In this case the government is selling to consumers with relatively low- prices to influence the market prices and minimize the imported products.

The Egyptian government increases the importing regulations and increase custom decrease the availability of small importers to buy from outside especially from China. Imported home appliances import decrease by 23% of total country imports. That means that government influence on the market price is very significant.

Economic Analysis:

In order to secure the demanded quantities at favoured prices, the Egyptian government has signed several agreements with banks to give loans for importers who need to produce locally with low-rate loans. Despite the government policy to support and encourage local production, represented by the various programs of the Ministry of industry. On the other hand, the high inflation forces the customers to buy low price products.

Social Analysis:

Home appliance has been associated with Egyptian traditional activity for preparing new homes for marriage. The reasonable prices help poor people can prepare the homes with reasonable prices. It can be also viewed as a way of showing social status, especially young people. With the change in society, housewives became working mothers, who are under constant pressure to satisfy work obligations along with family requirements. The task of securing family services buys appliances. The high rate of population growth is an important factor in increasing the demand on products. However, the continuous increase in prices constitute a burden on the Egyptian consumer. So, the customers like to buy cheap products with any brand name. So, there is a trading companies appears in the last few years import products from Chinese OEM manufacturers.

Technological Analysis:

Despite the growing awareness against power consumption and efficiency of new products than the old, not to mention harmful to environment, they still use the old one for economic reasons. Technological advancement has penetrated in Egypt with a main objective of power and water consumption reduction. New alternatives have been introduced that offer similar or higher efficiency and durability with lower lifetime cost. Furthermore, new manufacturing

techniques have been adopted in factories to reduce the heavy need on labour, and hence reduce the total cost of production. AM offers concept of sustainability as well. It increases the production efficiency which conserves the resources. Material consumption is low with light weight design and less waste material cut-offs. AMT consumes less power than other production technologies.

7.2 Altitude towards AM Implementation in home appliances companies

In results part, we capitalize on all the above and target the GAP between AM and CM production for home appliances products. The obtained data from was collected and analysed from the two companies. There are three different parts had been used for describing the factors affecting AM implementation in production and four interviews with department managers are used for evaluation. The logic behind choosing the companies was to choose companies producing home appliances with previous experiences with AMT in production.

Company Overview

Company A is a leading company in the field of home appliances and one of the first companies to own AM equipment in Egypt. AM machines used mainly for prototyping serves the company and serve the local market with AM parts as well. The annual production of the company is about 2.4 million of products and the number of employees is about 2500.

Company B is a smaller scale company in the same field, but it is a market leader in the chest freezer in Egypt. It does not have AM machines however it outsources the service. The annual production is about 400,000 products and the number of employees is about 350. Company B had been chosen as a lower scale company regarding the production size and investment in R&D. and have the ability be OEM to produce customized product for B2B.

Table 4 Companies overview

Company	Part	Functionality	AM Propose of Use
(A)	Door Lock Hook (Washing Machine)	Functional part	Critical to quality
	Power Button (Electric Water Heater)	Aesthetic part	Special edition promotion
(B)	Door Handle (Chest Freezer)	Aesthetic part	Limited quantity for OEM product

Interviews Description

Four interviews had been performed during the project. The strategy for choosing the persons for interview is to make the interview with the manager of the department responsible for part design and manufacturing technology selection and the manager of prototype department responsible for AM part manufacturing. The interviews questions are in appendix. The companies have different target for applying AM and using different methods for printing parts as well. Interviews with managers in different positions in the two companies had been performed. The main objectives are to understanding current AMT of both companies. Knowing the availability of applying AM in production and the gains from the business. Moreover, evaluate the suggested methodology of implementation matching the procedures will be done in selected parts.

Table 5 Interviews and purpose of questions

Interview	Position	Purpose of interview
1	Company (A) Prototype Department Manager	- Provide AM equipment information - AM part selection and calculations
2	Company (A) WM R&D Department Manager	- The use of AM in the washing machine - The feasibility of use in production
3	Company (A) WH R&D project Manager	- The use of AM in water heater - The feasibility of use in production
4	Company (B) R&D Department Manager	- The use of AM in a chest freezer - The feasibility of use in production

First interview in company A consists of three meetings with three different department managers inside the company, AM department manager, washing machine R&D department manager, and water heater R&D department manager. AM department manager gave the machine and parts technical information. R&D departments managers are the responsible for applying AM in the product and preparing the required studies and analysis which help in taking the decision. So, they gave the information related to the part selection procedures and analysis. They collect the needed data from other departments.

The second interview in company B had been done with R&D department manager. the company produce the part at outsource supplier. All the information related the part selection and the procedures for applying AMT in the product was collected during the interview.

The interview questions for the interviews are in appendix section.

7.2.1 Case Study (1) – Company (A)

Interviews

Interview meeting 1 with AM department manager gave the machine and parts technical information. The department has two FDM AM machine large and small one. Both machines have two printing heads for part main material and support material. Both machines used for printing small quantities of plastic parts for prototypes ten years age. They start to produce thousands of parts for production one year age. The department have CNC milling machine used for producing dies and moulds inserts. There are other machines for post-production finishing and silicon casting equipment. The department use equipment in daily use for supporting all product design and production.

When we ask about the technical issues for AM operating settings the answer was it related to the part mechanical properties and surface finish. According to the application of the part, the machine parameters and post-processing to optimise between the produced part properties and its cost and production speed. The production actions start from part orientation on the printing platform and number of parts should be printed in each cycle. Then the machine operation parameters such as print speed and layer thickness. He added that the material selection is important for product hardness and printing speed. The part costing and operation time can be calculating easily using the machine software. the accuracy of part cost and building time is about 5%.

The company plan to expand the AM department by buying new plastic SLA machine and metal AM machine. The main investment in AM field is the training for engineers and operators. In addition to the highly attention to keep the learning level on both operating software and 3D modelling.

The interview proof that the technical part of the study is like the activities inside AM department. The part printing process is important for the part specifications, cost, and time.

Interview meetings 2 and 3 was done in products research and development departments. The interviews consist of three sections. The first was related to AM equipment, the result was similar in the most points. The AM is feasible when we try to produce small plastic parts with small quantities. The normal technology used is plastic injection which give a cheap part when comparing with AM parts however it needs expensive plastic injection mould for each part. The barrier for using AM in production are part cost and productivity. The current AM machines cannot produce production tools, but they produce it using CNC milling

machine which is a type of RP but not AM. The second section of questions were related to Part selection and design. They usually produce Small and light ABS parts for aesthetic and functional application in the final product. The limitation for using the technology is part size and part hardness. Dimensions and part quality control is measured by 3D scanner.

The third section was asking about the implementation plan. They agreed with the suggested steps. Organizational and product aspects are logic with the situation in the company when examine it of the parts produced with AM. The implementation plan can be applied in the company when applying AM in its products. The organizational aspects contain business and manufacturing strategies which give detailed logic steps describing the opportunities for the company and lead the company to prepare the business plan before starting to apply AMT. Design and human resources strategies is already done when the company made the decision to buy the machines ten years age and still investing in the resources.

AM Implementation methodology

- **Organization Aspect**

Business strategy

The company's business and operational strategy: General strategy is to produce high quality home appliances targeting class A customers. AM strategy is to produce customized facelift products

The company manufacturing paradigms is mass production but for AMT application it will be mass customization.

Identify the market opportunities and target customers for AM: Special edition products for market promotions of occasional offers and company direct sales showrooms.

Create a business model: Flexibility of producing few parts with small quantities change the brand proposition and match the customer needs for specific category with minimum investment.

Manufacturing strategy

Buy / make decision: Done – The company has its own machine. As we knew from interviews that the company plan to expand in AMT by investment in more machines.

Prepare a study of the first step of AM investment: Done – The company already start with AM in design validation.

Provide the productivity and improvement related data: Part (1) is the best example for productivity because it will prevent the assembly line stoppage. Part (2) is the good example for improving the product shape according marketing department needs.

Design Strategy

Design for AM starts with hiring high skilled designers: Done – Design office is available and supporting AMT.

AM machines are used first for a prototype in the validation phase: Done

- **Product Aspect**

Part Selection

Define the target parts list: Design Department collect the parts and prepare design alternatives for approval from marketing team.

Estimate the parts production volume: define marketing date.

Select suitable parts: Marketing team decision.

Part (1) – Washing Machine Door Lock Hook - Company (A)

Problem: The problem is a critical to quality problem occurs in the door mechanism.

Action taken

Modify the current design of the part. Five alternatives of modifications are generated.

Use 3DP to build the prototypes for test. Build 10 pieces from each design for test.

Test the three alternatives until reach the best results. Select the part for production.

Produce a trial batch of a hundred of pieces for the statistical results check.

Produce ten thousand parts using AM technology for repair the defected products and normal production until the mould modification.

Parts designer considered to plastic injection moulding roles because the parts normally produced by plastic injection and both parts are used for similar functionality.

AM Part Cost Assessment

The cost model was developed for comparing the production costs of plastic parts using FDM and plastic injection moulding part which bought from outsourcing supplier. Plastic injection parts costs can be considered as the reference costs meanwhile this price is the

standard part for the normal production. The mould price will be taken in consideration for calculating the investment cost.

When comparing AM part cost with normal part cost breakeven point quantity the plastic injection will be high and decreasing by increasing the produced quantities.

Cost of AM Equipment (Machining Cost)

Machining cost can be calculated for the printing cost per hour. The machine depreciation price can be calculated for 5 years.

Table 6 AM Machining Cost (Company A)

Machine Price [Euro]	16500
Machine depreciation [years]	5
Machine depreciation per year [Euro/year]	3300
Machine maintenance cost per year [Euro/year]	1000
Total machine cost per year [Euro/year]	4300
Annual operating hours (hr)	2000
Machine operation Cost [Euro/hr]	**2.2**

Door Hook Cost

Part total cost consists of the summation of machining cost and material cost. The total part cost when producing it by AM is 0.36 Euro however the original part price which purchased from external supplier is 0.25 Euro. So, the loss between the two product is 0.11 Euro when we produce the part using AMT.

Table 7 Part / Machine Operation Data

Machine platform size [mm]	600 × 600
Part footprint on building platform [mm]	40 × 20
Number of parts per platform	450
Platform build time [hr]	48
Part Machining Cycle time [hr]	0.11
Part Machining Cost [Euro]	**0.24**

Table 8 Labour Cost

Labour cost per hour [Euro/hr]	7
Setup time to control machine [hr/Platform]	1
Post-processing time [hr/Platform]	3
Labour cost per platform [Euro]	28
Total Labour Cost per Part [Euro]	**0.06**

Table 9 Material Cost

Material price (ABS) [Euro/Kg]	25
Part weight [gm]	2
Support structure Weight [gm]	0.5
Total Material cost per part [Euro]	**0.06**

Table 10 Total Part Cost

Total cost per part [Euro]	**0.35**
Defective parts ratio [%]	0.50%
Total Part Cost [Euro]	**0.36**
Original Part Price (Outsource supplier – Injection Moulding)	**0.25**
	42%

Assembly line Stoppage loss

Produce the part using AM prevent the assembly line stoppage. The stoppage losses cost can be calculated by calculating the daily fixed cost for the assembly line.

Table 11 Assembly Line Stoppage Cost

Annual Fixed Cost	3 400 000 Euro
Daily Fixed Cost	13 600 Euro/day
Daily Production	800 Unit/day
Stoppage period needed for modify production tooling	3 days
Fixed cost for produced unit (Fixed cost / Unit) = 13600/800	**17 Euro**

We can sum up that the company will lose daily the amount of daily fixed cost which is 13600 Euro per day. the cost calculations shows that the loss in each part of AM is only 0.11 Euro. This means that the applying AM with higher part cost can eliminate the loss due to assembly line stoppage. The total stoppage cost in 3 days is equal to 40800 euro however the increasing in part cost is only 264 euros.

Part (2) – Power Button Cover

Company (A) – Electric Water Heater – Aesthetic part – Special edition promotion.

Problem: Marketing team need to produce a special edition water heater as a mothers' day promotion for the company's direct sales showrooms and shops. The target quantity is five thousand of the new products. The original part is produced using plastic injection moulding machines. The target is to produce the required quantity for this occasion in March.

Action taken:

Industrial design team generate 3D drawings for Three alternative designs. 3DP built the prototypes for approval. The price calculated for the produced parts. AM Department produced three thousands of parts using AM technology for assembly line according to plan.

Power Button Cover Cost

There are two alternatives for producing the part the first one is to produce it using AMT. the other alternative is to buy a new plastic injection mould for the new design.

AM Part total cost consists of the summation of machining cost and material cost. The total part cost when producing it by AM is 0.72 Euro however the original part price which purchased from external supplier is 0.41 Euro. So, the loss between the two product is 0.31 Euro when we produce the part using AMT.

Table 12 Part / Machine Operation Data

Machine platform size [mm]	600 × 600
Part footprint on building platform [mm]	30 × 30
Number of parts per platform	400
Platform build time [hr]	93
Part Machining Cycle time [hr]	0.23
Part Machining Cost [Euro]	**0.50**

Table 13 Labour Cost

Labour cost per hour [Euro/hr]	7
Setup time to control machine [hr/Platform]	1
Post-processing time [hr/Platform]	4
Labour cost per platform [Euro]	35
Total Labour Cost per Part [Euro]	**0.09**

Table 14 Material Cost

Material price (ABS) [Euro/Kg]	25
Part weight [gm]	4
Support structure Weight [gm]	1
Total Material cost per part [Euro]	**0.13**

Table 15 Total Part Cost

Total cost per part [Euro]	**0.71**
Defective parts ratio [%]	1%
Total Part Cost [Euro]	**0.72**
Original Part Price (Outsource supplier – Injection Moulding)	**0.41**
	75%

New Mould Investment

When purchasing new plastic mould for the new part instead of AM. The mould price is 5000 Euro, and the part cost is 0.41 Euro. For evaluating the two alternatives, it is important to calculate the critical quantity which needed to cover the mould cost. The critical quantity is 16129 parts which means that if the quantities of this design less than the critical quantity, it is better to use AM for producing the part. If the quantities are more, so we should buy new mould for that par.

Table 16 Critical Quantity

New mould price [Euro]	5000
Critical Quantity Q* [Parts]	16 129

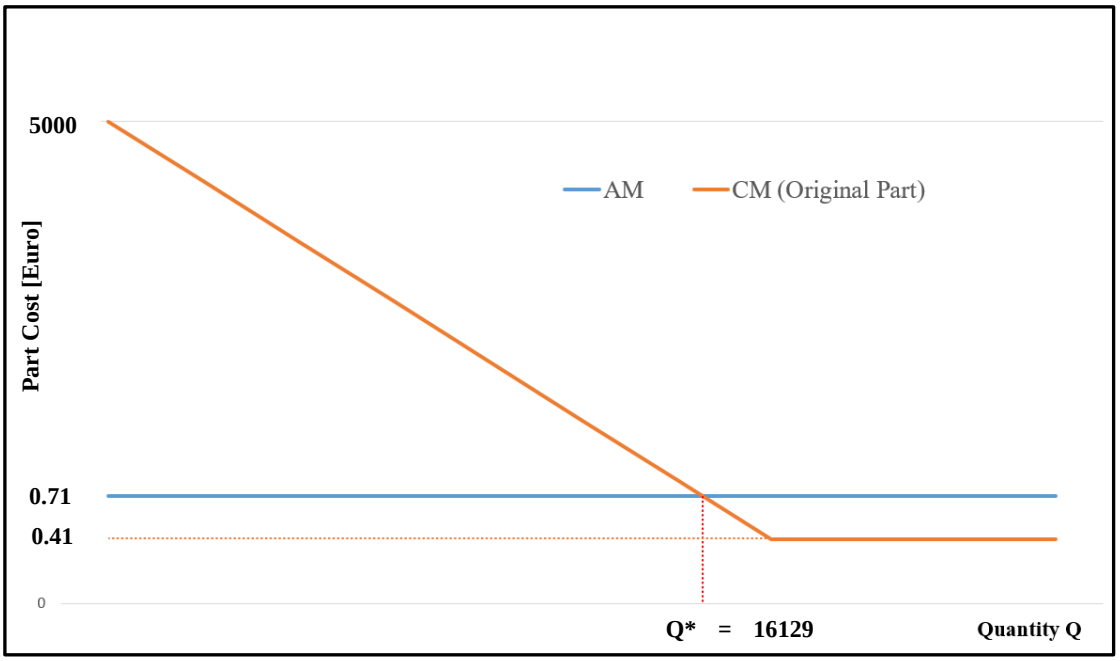

Figure 40 Part 1 BEP and critical quantity

Factors affecting AM Application in production

When producing Part (1) & Part (2) using AM:

Reduce time to market to be one day instead of days for modification of the plastic injection mould.

Solve the supply chain issue which avoid assembly line stop.

The manufacturing paradigm will be changed from mass production to mass customization for the small batch.

7.2.2 Case Study (2) Company (B)

Interview was done in company B with research and development manager. the AM applied in the product for assemble small parts for special orders sometimes. He response that AMT is more economic and save investment when we plan to produce number of thousands of parts. They select the part with an expert judgement for part specifications. The decision of buying machines is not done yet. They buy the part form local supplier. Some the service is easier and cheaper than investing in machine and technicians inside the company. His opinion about the implementation plan that the alternative of buy the part from local supplier should increase to add some activities related to supplier qualification. The training for design engineers for design for AM is a first decision should be taken from the top management. The service can be easily gotten it as outsource.

AM Implementation methodology

- **Organization Aspect**

Business strategy

- The company's business and operational strategy: General strategy is to produce home appliances targeting class B customers. AM strategy is to produce with customized parts for OEM production.
- The company manufacturing paradigms is mass production but for AMT application it will be mass customization.
- Identify the market opportunities and target customers for AM: OEM customer needs.
- Create a business model: Flexibility of producing few parts with small quantities change the brand proposition and match the customer needs without investment.

Manufacturing strategy

- Buy / make decision: Make – The company outsource the part supply. As we knew from interviews that the company plan to start investing in AMT within two years.
- Prepare a study of the first step of AM investment: short term – outsource the service. Long term – invest in buying FDM machines.
- Provide the productivity and improvement related data: Part (3) is the best is the good example for improving the product shape.

Design Strategy

- Design for AM starts with hiring high skilled designers: long term – Design office need design for AM and AMT trainings when buying AM machine.
- AM machines are used first for a prototype in the validation phase: long term plan.

- **Product Aspect**

Part Selection

- Define the target parts list: Design Department collect the parts and prepare design alternatives for approval from OEM customer.
- Estimate the parts production volume: define sales date according OEM sales orders.
- Select suitable parts: Design Office with OEM customer decision.

7.2.3 Part (3) – Chest Freezer Door Handle

Company (B) – Chest Freezer – Aesthetic part – Limited quantity for OEM batch.

Problem:

The chest freezer door handle consists of two separate parts, cabinet part and door part. The cabinet part contains the product brand name. The original part for normal produced by plastic injection moulding. The part material is ABS and finished with vacuum coating.

The company produces the chest freezer under its brand name and at the same time produces it with different brand name for other customers as OEM Original Equipment Manufacturing. The problem is the need to produce OEM handles with a specific brand. AM solved the problem by printing the handle with the new brands.

Action taken:

1. Design team generate 3D drawing for cabinet part with the required brand name.
2. The company do not have 3DP machine but outsourcing the service.
3. Purchasing department is the responsible for ordering the parts for assembly line according to batch sizes production plan. The quantities range is from two to five hundreds per batch.

Chest Freezer Handle Cost

Similar to the previous part, there are two alternatives for producing the part the first one is to produce it using AMT. the other alternative is to buy a new plastic injection mould for the new design.

AM Part in this case will be purchased from local supplier. The AM part price is AM is 2.30 Euro however the original part price which is plastic injection and purchased from external supplier is 1.50 Euro. So, the loss between the two product is 0.80 Euro when we produce the part using AMT.

Table 17 Total Part Cost

AM Part Price (Buy from outsource supplier) =	**2.3**
Original Part Price (Buy from outsource supplier) =	1.5
	57%

New Mould Investment

When purchasing new plastic mould price is 8000 Euro and the part cost is 1.5 Euro. For evaluating the two alternatives, it is important to calculate the critical quantity which needed to cover the mould cost. The critical quantity is 10 000 parts which means that if the quantities of this design less than the critical quantity, it is better to use AM for producing the part. If the quantities are more, so we should buy new mould for that par.

Factors affecting AM Application in production

When producing Part (3):

Reduce time to market to be one day instead of months for producing plastic injection mould.

Solve the supply chain issue buy reduce order time.

The manufacturing paradigm will be changed from mass production to mass customization for the small batch.

Table 18 Critical Quantity

New mould price [Euro]	**8000**
Critical Quantity Q* [Parts]	**10 000**

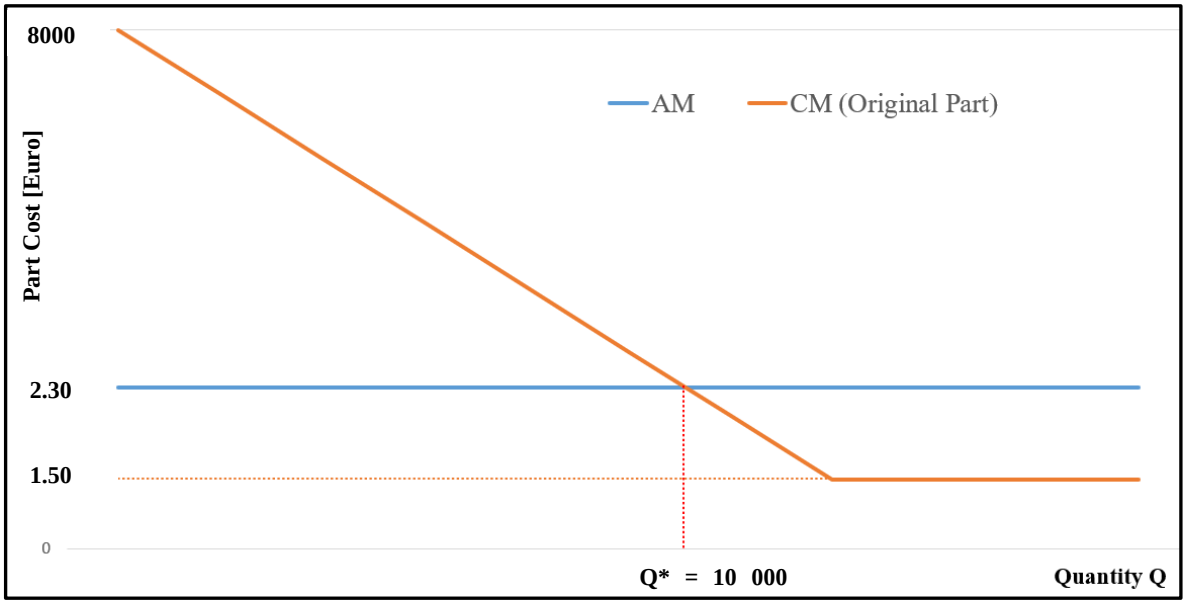

Figure 41 Part 2 BEP and critical quantity

8 SUMMARY OF ANALYTICAL FINDINGS

Based on the analytical part of our study, Governments encourage the companies to apply AM because of great benefits on industries and markets. The high volume of production of home appliances sector makes the application of AM is difficult. However, by analysing the product market we found that there is a great opportunity to apply it in some specific scenarios. By analysing the Egyptian market by using PEST analysis methodology, the result gave a new market opportunity for B2B business. Due to the importing restrictions which had been done by the government there is a great market starts to produce special orders with limited quantities for the traders as OEM instead of importing the products. The characteristics of this market share for other competitors and the payment is in advance. Another important reason for using AMT is to eliminate the assembly line stoppage when quality or logistic problem appeared.

Based on our study and results, we classify the AM project as a low-risk project, despite the high initial investment. keeping in consideration that choosing the parts to apply AM in our products required for best results. We understand the risk we have in B2B coming from the OEM customers that some of them tends to make a backward integration for having their own manufacturing business, yet this is one of our strongest points for experience, cost focus, high quality products and after sales services. we make our products that make us the best choice to supply B2B. Additional investment in AM equipment can be eliminated by outsourcing of the service. It allows for utilizing existing resources with minimal investment to improve the consolidated net profit. However, the experienced and training persons are important for product design, feasibility, and support.

In home appliances AM technology is applied in prototyping of components for acceleration the new product development process. It can be applied in some special parts in production. these parts should be suitable to produce with available AM machines.

AM implementation methodology consists of actions should be done before applying AMT. These actions are divided into two categories, organizational aspect actions and product aspect. The organizational aspect contains the business strategy and the manufacturing strategy of the company. The product factors must be considered when deciding about AM implementation. For example:

- Selected part specification such as size of produced parts and production volume.
- Material used for production and possibility to use AM with the same properties.

- Required part flexibility (production with highly changing requirements is more suitable for AM, because despite its higher price, company can fulfil all requirements within a short time)
- People skills (being able to work with AM)
- The feasibility study and part cost analysis should be performed to can calculate the break-even point for critical quantity. Critical quantity is the part quantity at which the AM is feasible to apply in product.

8.1 Interviews results

As mentioned before, the companies have different target for applying AM and using different methods for printing parts as well. The interviews shows that there are many value-add for the business when applying AM. The values in enterprise profit with different way. the profit comes by increasing the sales or minimize the expenses. The production needs to change the design and apply the modifications immediately can be an asset for the company. So, the mandatory action that should be taken is to invest in the training for how to apply AMT in products because AM can solve many problems.

AM production can be produced inside the company, or it is very easy to find many qualified suppliers. It depends on the ability to invest in AM and the experience of the technology inside the company design department. The suggested implementation plan in our research is similar to the plan that the companies use while applying this new technology in production.

First case study, produce a special edition product for targeting a new customer segment, the selling prices in this model are more stable and are determined by the seller. In addition to quality and after sales services of products provided by the manufacturer are key factors in determining the selling price levels and production stability. Model is a B2B market (business to business), One of the characteristics of such a market is that payments are made in advance. Therefore, economy of scale plays an important role. Buyers usually buy large number of products and settle payment with his order to get a more favoured price and reduce the order shipping period.

9 METHODOLOGY FOR APPLYING AM IN PRODUCTION

AM implementation in a company starts when the company trust the new technology as a production tool and understand the technology very well then it will be easy to evaluate its current state situation and know how to gain business profit. Implementing a new technology in a business is hard as starting the business itself. It must find a way for gaining the knowledge and technology know-how then make the suitable adaptation needed inside the company and in its products as well. There are many activities to define the new products families, reorganize the company structure, production roles, team training. The AM implementation project start with the preparation stage which is important for understanding the technology and its benefits and the barriers for application in our business. AM business plan with feasibility study help the top management in the strategic decisions related to the vision and new investments required and other related decisions. So, to proof that the implementation plan can be applied on any company need to apply AM in its products. The organizational aspects contain business and manufacturing strategies which give detailed logic steps describing the opportunities for the company and lead the company to prepare the business plan before starting to apply AMT. Design and human resources strategies is already done when the company made the decision to buy the machines ten years age and still investing in the resources.

Based on the theoretical and analytical parts findings which discuss in detail the implementation process for company for applying additive manufacturing in a product. This part of the study proposed detailed procedures for consumer goods especially home appliances business. we will go thought each individual point and describe how the company should work as a result of our case studies.

As described in application of AM chapter, companies start to evaluate their products to find the parts or subassemblies matched with AM and catch the benefits can be added to its business and introduce the opportunities of AMT.

9.1 Organization aspect

Organizational aspect activities in a company starts from the thrust that the AM is a new technology so the risk is higher than other manufacturing technology and then the other activities can be started with redefining the vision of the company future by using the new technology and organization structure. The management control and people support for the awareness of the AM potentials is important.

Business strategy

- Mass production is the common production paradigm in our two case studies to meet minimum product cost, customer needs and sales plan. The company define mass customization paradigm as a new strategy for producing special orders for specific quantity for selective situation. AM help the operations to introduce a customized products quickly with low investment.
- The marketing department should be aware with market changing and immediately share the information for new products requirements. Design can be rapidly changing without investment in new moulds using AM. So, AM can bring this benefit to the business to be fast for new product launch to market than the competitors.
- Business model Creation for developing the business case and defining a specific area for profit to cover the increased cost by applying AM.

Manufacturing strategy

The right initiations of AM in a company especially with correct manufacturing strategy could contribute to the organization performance and long-term competitiveness in the future. Otherwise, it may stop the use of AMT in the future.

- AM feasibility study and business plan give information for Buy / make decision to decide whether to invest in machines or outsource the service because the AMT risk and uncertainty are high, and it needs large investment in equipment, processes, and training. When the company start to invest in AMT it will be able to control the process very well and the learning curve of the stuff will be grown quickly. as in company A, the company use AMT as a standard tool in prototype and start to use it in production as well in production.
- Define the entry point of the technology. a study of the first step of AM investment as the technology entry point. Company A start to buy small machine for FDM then expand the investment in other machine in this production cell.
- AM can improve the productivity when we use in eliminate the stoppage of assembly line. As we describe in case studies, the problem in assembly line can be solved by producing the part immediately. The situation of line stoppage happens many times a year during production due to quality problem in parts or supply issues. During this year this happen three times. First was stop due to logistics problem happens in top

panel fastener which is a plastic part fixing the upper top panel of washing machine. AM used for producing this part to solve the problem. The assembly line may stop as a reason of the problem for 5 days. It is the time for air fright of the part from outside. The other similar scenario happens when the detergent drawer syphon plug had a problem. the line stopped for 3 days until the mould modification done. The AM part production is more expensive but comparing with stoppage loss it will be more profitable for the company. AM log file generated for the company for collecting the line stoppage problem. Table 19 is very useful to know the annual savings due to applying AM.

Table 19 Line stoppage list during the year 2022 log file

Part	**Door Hook (Case study)**	**Top panel plug**	**Syphon plug**
Common part price [EURO]	0.25	0.15	0.42
AM cost [EURO]	0.36	0.32	0.60
No. of Pcs per product [Pcs]	1	2	1
Increasing in part cost [Euro]	0.11	0.17	0.18
Stoppage period [days]	3	5	3
Daily production [product/day]	800	800	800
Total AM parts [Pcs]	2400	8000	2400
Total increasing in cost [Euro]	264	2560	1440
Daily Fixed Cost [Euro]	13600		
Stoppage cost [Euro]	40800	68000	40800
Saving [Euro]	**40536**	**65440**	**39360**
Total Saving [Euro]	**145336**		

Design Strategy

- Design team give more attention when designing new products to Design for AM roles and techniques as an alternative method of production in case of problem may happens during normal production. AM machines are used first for a prototype in the validation phase.

  Hired skilled designers should have special skills and experience such as:

  - 3D modelling with experience in design for plastic and metal AM parts.
  - Experience in defining parameters AM machines and part defects troubleshoot.

  Assign new training courses related to AM for the AM team and all employees work with the new technology. Table 20 shown the training matrix assigned to employees in company A and add the training to the continuous training courses list in HR

Table 20 AM training matrix

Training type	**Description**	**AM production**		**Design Engineer**	**Quality Control**
		Engineer	Operator		
Introduction to AM	AMT fundamentals and applications	✓	✓	✓	✓
Design for AM	AM Design AM technology selection AM material selection	✓		✓	
AM Advanced design	Generative Design Design complex AM Part consolidation			✓	
Advanced Measurement	Advanced measurement instruments	✓		✓	✓

- Assign AM team is the team from different departments work with AM.

  AM Team Departments:

  Design

  AM & prototype

  Production

  Quality Control

  Purchasing

  Marketing

  The responsibilities of AM team Manager and members:

  Managing implementation projects of AM inside the organization.

  Support all manufacturing operations.

  Attend the product development process.

  Data collection for production capabilities, activities, and volumes.

  Identify the parts for starting production with AM.

  Prepare the production process sequences.

9.2 Product Aspect

- AM team start with defining the target parts list to perform technical analysis and part assessment. This list contains the part specifications, alternatives for production, and estimate production quantities for each alternative. Select suitable parts for implementing AM in production. Perform parts technical assessment. Consider the factors affecting the AM cost reduction. In case studies for example, the parts list should contain part specifications, normal production and AM production information. During the project we prepare the list of parts suitable for production with AM. This list important for using when we need accidently need to apply AMT. New part assessment form was generated for collect all the part AM information the form shown it the following table 21. The form attached to part drawing and specifications to be ready for applying AM when needed. For the parts need to redesign again. The new design drawings and specifications are attached to the current drawings. This tool will help in make a complete assessment for the product and choose the suitable parts suitable for AM.

Table 21 Part Assessment Form

<table>
<tr><td colspan="3">Part Name: ……</td><td colspan="3">Part Code: ……</td></tr>
<tr><td>Part Function:</td><td colspan="2">☐ Aesthetic</td><td colspan="2">■ Functional</td><td>☐ Structural part</td></tr>
<tr><td>Part Type:</td><td colspan="5">■ Part ☐ Assembly
……...……</td></tr>
<tr><td>Material</td><td colspan="3">☐ Metal ■ Plastic
Material Type: …….……..</td><td colspan="2">■ Single materials
☐ Different materials</td></tr>
<tr><td>Part Size</td><td colspan="5">Length = ……. × Width = ……. × Height = …….</td></tr>
<tr><td>Design Complexity</td><td colspan="2">☐ Low</td><td colspan="2">■ Medium</td><td>☐ High</td></tr>
<tr><td>Post-Processing</td><td colspan="2">Colour
……..</td><td colspan="3">surface finish: Smooth/textured
……..……..</td></tr>
<tr><td colspan="6">Final Result: …….. ■ Suitable For AM
…….. ☐ not suitable for AM
…….. ☐ need modifications
……...……...
……...……...
……...……...
……....</td></tr>
</table>

Table 22 AM Part list washing machine product

Part	Weight	CM (Plastic injection)		AM (FDM)	
		Price [EURO]	Material	Price [EURO]	Material
Door hook	2 gm	0.25	ABS	0.36	ABS
Door handle	13 gm	1.5	ABS	2.34	ABS
Syphon plug	5 gm	0.60	PP	0.87	ABS
Top panel plug	2 gm	0.22	pp	0.32	ABS
Pump cover	15 gm	1.65	ABS	2.30	ABS
Hose support	6 gm	0.68	PP	1.09	ABS
Buttons	4 gm	0.5	ABS	0.72	ABS
Knobs	8 gm	0.90	ABS	1.44	ABS

- Part design for AM: select the part suitable for AM from AMT point of view according to the following aspects. Modify the design of the part for AM.
- AM technology selection and material Selection by using Table 1. The table describe specifications and material for each technology. Parts in case studies used FDM machine because it is the machine in company.

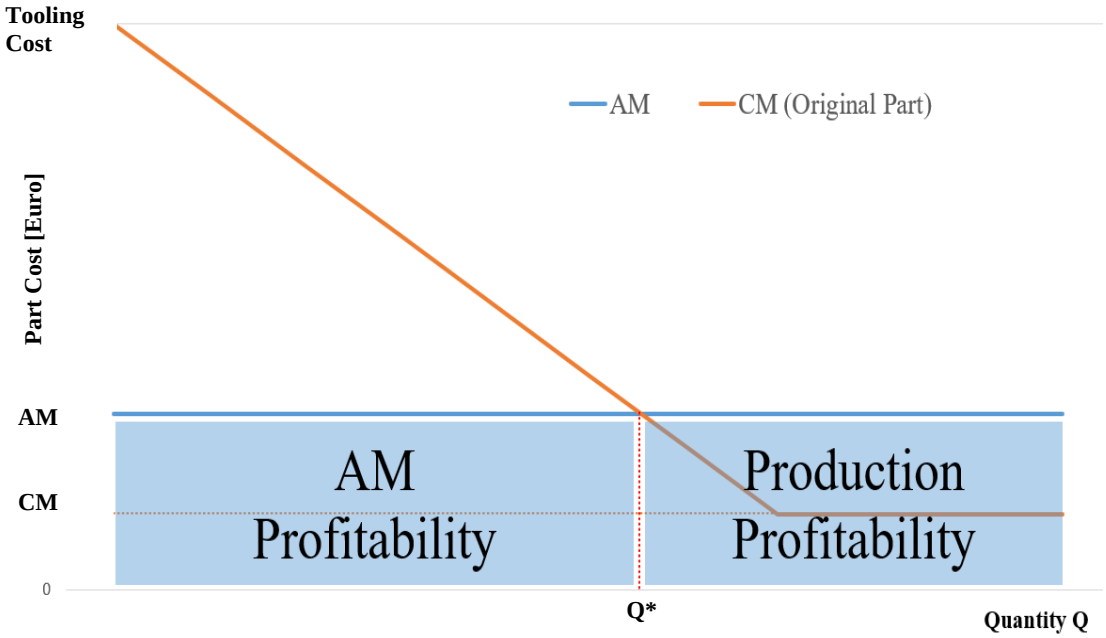

Figure 42 AM Profitability Zone and critical quantity

- AM Time Estimation: Theoretical cycle time is calculated by the machine software.
- AM generally more expensive than injection moulding however when we produce new mould for the new product it will be very expensive for small quantity of production. AM do not need any mould it just makes new part design and print the required small quantity for production.

9.3 RIPRAN Methodology

This part focuses on the RIPRAN method, which focuses on the processing of the risk of the project. risk as a process by which the following steps are taken:

- Risk analysis: Strategy of risk management and preparing the risk analysis.
- Risk identification: Identification the existing and possible threats risks that the project may face. The risks may be human, operational, reputational, project, financial, technical, nature, political, structural risk.
- Risk quantification: Quantification of the risk by calculating both likelihood of risk and the possible impact.

$$\text{Risk Value} = \text{risk probability of occurrence} \times \text{risk impact}$$

- Risk response: Response to risk by avoiding, accepting, or controlling it when happening.
- Overall risk assessment: General assessment of risk.

Table 5 contains RIPRAN method which include the risk analysis, response, and risk assessment. Suggested solutions for minimize the risk are described in the table.

We can categorize the risk of the technology implementation in a company into two categories management threats and technology threats. The management threats happen when the company management is not interested in the technology or it cannot fund for investing in AM. Fail to sell the product is a managerial problem as well. It may happen due to lag of project plan at the beginning or wrong product definition according market needs. Technology threads cover all the AMT and the product technical issue such as product quality problems due to material, production, or technology knowhow. the technology threats also happen due to wrong product pricing, costing or supply problems.

Table 23 RIPRAN analysis

No.	Threat	Scenario	Occurrence Probability 0-1.0	Impact 0-10	Risk Value	Solution
1	Lack of interest of management	Impossibility of project implementation	0.10	10	1	The threat Can affect the project, but the value is low
2	Lack of funds	There is no sufficient Financial Resources	0.20	5	1	There is another alternative to outsource service
3	Insufficient training	Insufficient qualified employees, impossibility of implementing AM in current product or create CAD drawings	0.50	10	5	Provision of regular courses on AMT and 3D modelling
4	Non-compliance with the budget	Incurred additional costs, material price increases	0.10	5	0.5	Consistent implementation and control of budget prices, verification of prices at suppliers
5	Purchase AM Services of a professional Company	The service will be more expensive than internal production	0.1	3	0.3	Verify prices from different vendor during cost analysis
6	Poor quality Parts	Part will be non-functional; Production will be inefficient	0.30	8	2.4	Selection of suitable parts for AM and materials
7	Lag of sales orders for AM products	The company will not provide suitable orders for AM product	0.5	8	4	Product definition according customer needs during study

CONCLUSION

Based on the findings from analysis, research question answers are presented in conclusion. First, "What is AM and the application of AMT use in manufacturing organization?" Additive Manufacturing AM is to produce physical products from CAD drawing. AM has different terms to describe it such as 3D printing 3DP. AM has different methodologies to produce a part. The most effective way of categorization is to categorize the overview according to material. AM is used mainly in aerospace, automotive, healthcare and consumer goods industries. AM mainly used in two purposes: New Product Development NPD and small production quantities. Second, "What are the key factors affecting the implementation of AM in production?" it was found that the AM gives great values to the manufacturing organization. AM enables high level of creativity and increased product design freedom and complexity. AM reduces time to market. It produces the lightweight part with minimum quantity of material used and less scrape. It can change the manufacturing paradigms from mass production to mass customization. Third, "How do those factors impact the implementation of AM in production?" the factors affect the application of AM are important to keep while perform a successful business model. The high manufacturing cost of the AM part can be accepted due to other values can be gained in the business. Finally, "What is the methodology for applying AM in production?" implementation action plan consists of organization and product aspects. The organization aspects are helping for good understand of the organization business and the market opportunities to stablish the market demand and target customers' needs. Create a business model and develop the business case with specific area for profit will be a reduce the risk and uncertainty of the new technology. Product aspects are very important for selecting and redesign the new part for AM value add, machine selection and part cost. Define the target parts list to perform technical analysis and part assessment. Estimate the parts production volume. Select suitable parts for implementing AM in producing or production. Perform parts technical assessment. Consider the factors affecting the AM reduction.

Additive Manufacturing AM gives several advantages for low volume production; however, it is difficult to use AM in mass production. It is profitable and time efficient when producing small batches and using it as a supportive tool when a need to produce small batches for marketing purpose or solving a quality problem to decrease the expenses of assembly line stoppage as the case studies illustrated.

Feasibility for use AM can be quantitative by cost assessment of AM parts and can be qualitative as we can minimize some problems may happen. The cost assessment usually needs to calculate BEP which give the critical quantity which indicate the suitable situation for applying AM. companies that have AM machines can easily outsource the service. Desktop 3DP is cheap and do not need expensive support system so companies can start investment easily. It is enough for producing aesthetic parts with low tolerance. Interviews helps to validate the implementation plan. The technology goes cheaper and efficient for both the machine and material.

Finally, we aim to keep focus in AM mass customization model as an important step of future production digitalization and a first ramp up phase to get reach to the global AM target to use AM as the common solution in mass production. AMT as a new technology is not simple to implement in production of home appliances business however it is commonly used for decades in prototyping. The main problem face AM is the high volume of production. AM techniques in production which facilitate the produce OEM products for the exporters who can replace the imported products and buy the product locally with his brand name directly from local manufacturer, and hence reduce the import and the investment turnover.

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LIST OF ABBREVIATIONS

3D Three-Dimensional

3DP Three-Dimensional Printing

AM Additive Manufacturing

AMT Additive Manufacturing Technology

B2B Business to Business

B2C Business to Customer

BEP Break Even Point

CAD Computer-Aided Design – refers to the tool for generating 3D drawings

CF Chest Freezer

CM Conventional Manufacturing – refers to traditional manufacturing methodology

FDM Fused Deposition Modelling – refers to the standard technology of material extrusion for 3D printing

FF Modify Familiar technology for Familiar market in R&D projects

FN Modify Familiar technology for New market

NN Introduce New technology for New market

NF Introduce New technology for Familiar market

OEM Original Equipment manufacturer – refers to the product which produced by manufacturer with customer brand name

R&D Research and Development

RM Raw Material – refers to the original form of the material before machining

WH Electric Water Heater

WM Washing Machine

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APPENDIX I

Interview 1 Questions – Company (A) – Prototype Department Manager

AM Equipment - What equipment do you have in the prototype lab? - What is the main usage of AM equipment? - How often do you use the AM machines? - What type of finishing do you use with AM machines? - Do you change the printer settings according to the part requirements and/or quality? - Do you see an opportunity to expand the AMT in the company? - Does the company plan to expand the AM business? - If you need to buy new AM machines, which types of machines you will buy?
Part and material - What are the available materials you use in AM machine? - Which part category do you print, (functional/aesthetical / others)? - What are the parts you cannot print? - What are the part limitations for the printing process? - What are the available materials you use in AM machine?
AM implementation - Who is then responsible for calculating theoretical part cycle time and cost? - How far do the theoretical time and cost differ from the actual measured time and cost? - Who is responsible for the booking and planning? And how do you handle the machine schedule? - What equality procedures and methods do you use with AM parts? [QC / QA] - What kind of training does your company give to AM team? - What is the most difficult factor for large patch production with AM? - What are the AM limitations for mass production with AM?

APPENDIX II

Interview (2) Questions – Company (A) – Washing Machine Design Manager

Interview (3) Questions – Company (A) – Water Heater Design Manager

Interview (4) Questions – Company (B) – Design Manager

Implementation methodology
- Does your use AM in production?
- What is the main usage of AMT?
- Does the company plan to expand the AM in production?
- What is the feasibility of use of AM in production from your point of view?
- Who is the responsible for selecting parts and project feasibility?
- What is the most important factor that affects the implementation of AM in production?
- Which part category do you print, (functional/aesthetical / others)?
- What are the part limitations for printing?
- What is the importance of lead time for manufacturing tooling (dies, molds, jigs)?
- What is your part selection technique for AM "Open discussion about part selection"?
- What type of material do you use?
- Which output do you send to the prototype department?
Quality issues
- Which is the design validation process do you use with AM parts?
- What quality procedures do you use with AM parts printing?
- Is the quality methodology the same for normal production and product with AM part?
- Does your company assign AMT related training for your team?
Marketing issues
- How can the use of AMT change the marketing strategy?
- How can the use of AMT change the company final product family?
- How can the company target new customers by using of AMT in production?