TecnoCampus
Escola Superior
de Ciències Socials i de l'Empresa

Centre adscrit a la
Universitat Pompeu Fabra Barcelona

How Additive Manufacturing is shaping Global Supply Chains

Student's name: Sergio Martos Gutiérrez

Tutor's name: Valeria Bernardo

20-June-2021

MEMÒRIA DEL TREBALL FINAL DE GRAU

Course: 4th

Studies: Logistics and Maritime Businesses

ABSTRACT

Additive Manufacturing (AM), the term triggered from 3D printing, is leading the automotive sector, the EU's number one investor in R&D, towards a more sustainable, advanced, and efficient industry. This technology roots from the ongoing current automation of traditional manufacturing known as Industry 4.0 and it is currently being object of investigation and investment from most of the car manufacturers. The use of AM is embracing different fields in the industry, quite common in the prototyping application but approaching the idea of being adopted for series production. The purpose of this thesis is building a potential scenario up where AM is configured within the current global supply chain layout. To achieve this goal, it is considered a real innovation case conducted by an important car manufacturer where the resulted printed pieces are part of the paper's simulation. Paper offers a comparative between the conventional and the additive manufacturing and analyse economics and structural effects from adopting this technology at all levels.

RESUMEN

La Manufactura Aditiva (MA), término desencadenado de la impresión 3D, está guiando al sector de la automoción, el cual es el primer inversor de la UE en I+D, hacia una industria más sostenible, avanzada y eficiente. Esta tecnología surge de la actual automatización de la manufactura convencional conocida como Industria 4.0, que está siendo objeto de investigación e inversión por parte de los mayores fabricantes de coches. El uso de la MA abarca diferentes campos en la industria, comúnmente utilizado para prototipar, pero cada vez una idea más cerca de ser aplicada en la producción en serie. El propósito de esta tesis es crear un escenario potencial donde la MA se configura dentro del marco global de las cadenas de suministro. Para lograr este objetivo, se utiliza como referencia un caso real de innovación llevado a cabo por una importante marca de automóviles dónde las piezas impresas forman parte de la simulación del trabajo. La tesis ofrece una comparativa entre la manufactura convencional y la aditiva y se analizan los efectos económicos y estructurales de adoptar esta tecnología a todos los niveles

Keywords: 4th Industrial Revolution - Additive Manufacturing – 3D Printing – Sustainability – Globalization – Regionalization - Automotive Industry - Global Supply Chains – Technology.

Table of contents

1. Introduction

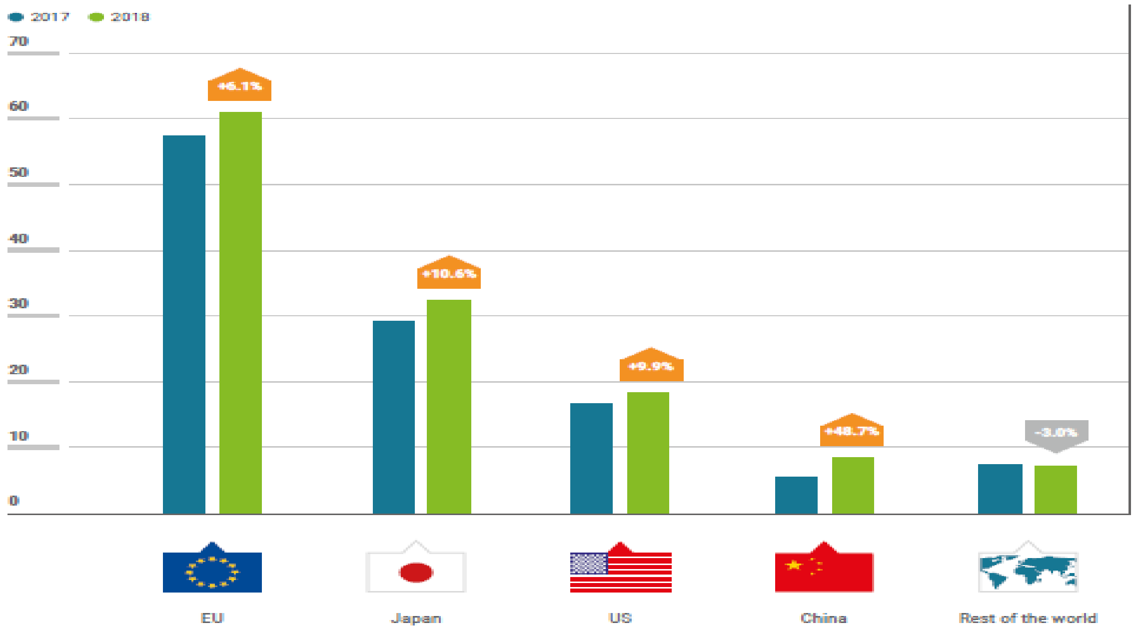
The 4th industrial revolution is happening right now and is growing at a fast pace. This new era is characterized by a range of new technologies that are fusing the physical, digital, and biological worlds. This revolution is closely connected with Industry 4.0 which is powered by the Artificial Intelligence, cloud computing, robotics, 3D Printing, Internet of Things, Industrial Internet of Things, and advanced wireless technologies, among others. Clearly, this new phenomenon aims at transforming the current world's industrial geographical distribution into a more sustainable pattern where the production assets return to North America and Europe, in other words, shifting the production from globalization to regionalization (Chen, 2016). The consequences are evident, digitalization is shaping the communication in all directions, changes in the layout of the current global supply chains are unavoidable and global transport is on the spotlight, in particular shipping, since transport is a derived demand (Bhasin and Bodla, 2016; Cohen et al. 2014; Steinberg and Karevska, 2019; Barz et al. 2016; Bell and Lyon, 2012; Mohr and Khan, 2015).

Regarding this context, Additive Manufacturing or also known as AM, but commonly known as 3D Printing, is playing an important role on this new revolutionary framework. Therefore, this thesis wants to study the properties of 3D Printing, benefits and consequences of its use, the implementation of this technology on the automotive industry and specially the impact on the logistics industry. Nowadays, COVID 19 has accelerated the integration of 3D Printing in the current manufacturing model to face the shortage of sources for materials and devices for a range of essential services, in particular for healthcare. Its capabilities definitely enable satisfying "on demand" needs which allow this technology being a real competitive advantage for emergency situations. (Choong et al. 2020)

In particular, this thesis pays special attention to the automotive industry, an industry specially driven by implementing new technologies and where additive manufacturing might play a transcendental role on those activities that require shorter lead times or that struggle with high complexity or customization. This technology is attracting the interest of large companies and it has already made further steps on car manufacturing since Urbee released the first prototype of 3D printed car body in 2011.

According to ACEA, the European Automobile Manufacturers Association, and Eurostat, Europe is the world region which is investing more intensively in R&D for the automotive industry as the following figure reflects. The investment has increased by 6.1% from 2017 to 2018 and the last published data ranks the investment in around €60.9 billion annually.

Figure 1: R&D investment in the automobile sector by world region



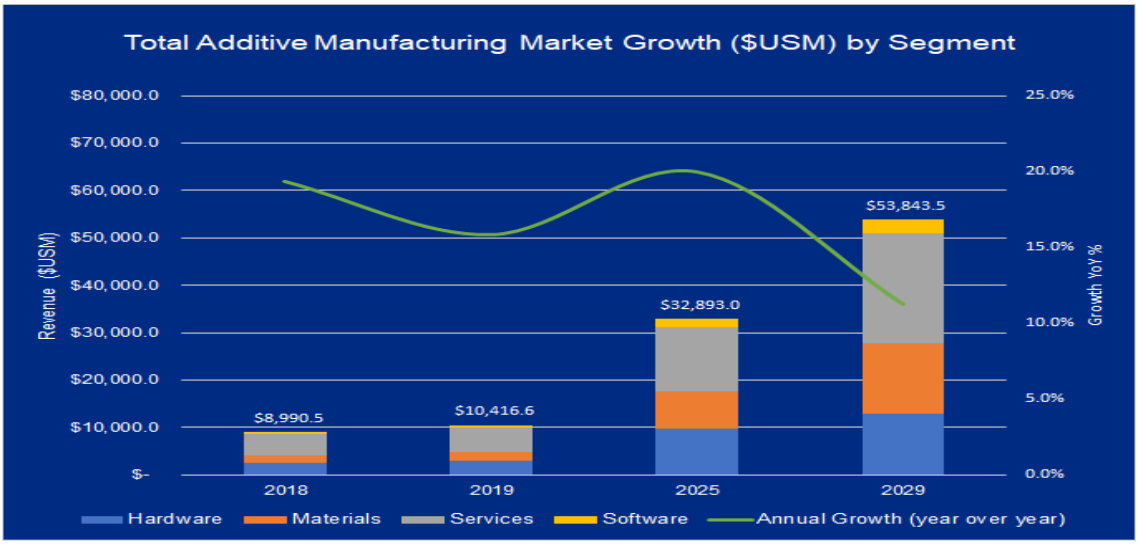
Source: Figure from ACEA and data from Eurostat

The main advantages of additive manufacturing mean a deep transformation of the current production and transportation global model, where we can simultaneously conceive the role of AM as a villain for global supply chains since the core purpose is eliminating the different intermediaries along the chain, heading the manufacturing as much closer as possible to the final customer. However, this new production model does not come up to completely substitute the traditional way but complementing and improving the conventional production techniques in certain industrial sectors. Therefore, the main goals of this thesis are defining the actual consequences of AM on logistics and supply chains and taking those current definitions of AM where the most shared expectative is a strong drop of global transportation and turning the other way round to those ideas and rethinking the proper meaning to additive manufacturing and how logistics can take advantage of this transcendental technology.

As we have already mentioned, this technology is becoming quite popular and it has a wide field of developing. According to the European Commission (EC), AM is receiving funding since the very first Framework Programme (FP) in 1984 and from that first programme has been done many others. For example, the FP7 more than 60 successful projects were funded, with over 160€ million of EC funding and a total budget of around 225€ million.

In order to reflect the widespread adoption and development of this technology we provide the following figures. Both figures, Table 1 and Figure 2, belong to the report from SmartTech analysis, a leading provider of market research and industry analysis in the additive manufacturing sector, the former shows that the global additive manufacturing market grow in 2019 to over $10.4 billion and AM has been growing at a fast pace from the expiration of the first patents in 2009. Forecast for the next decade are quite promising, reaching $53 billion by 2029 with the goal of penetrating production markets.

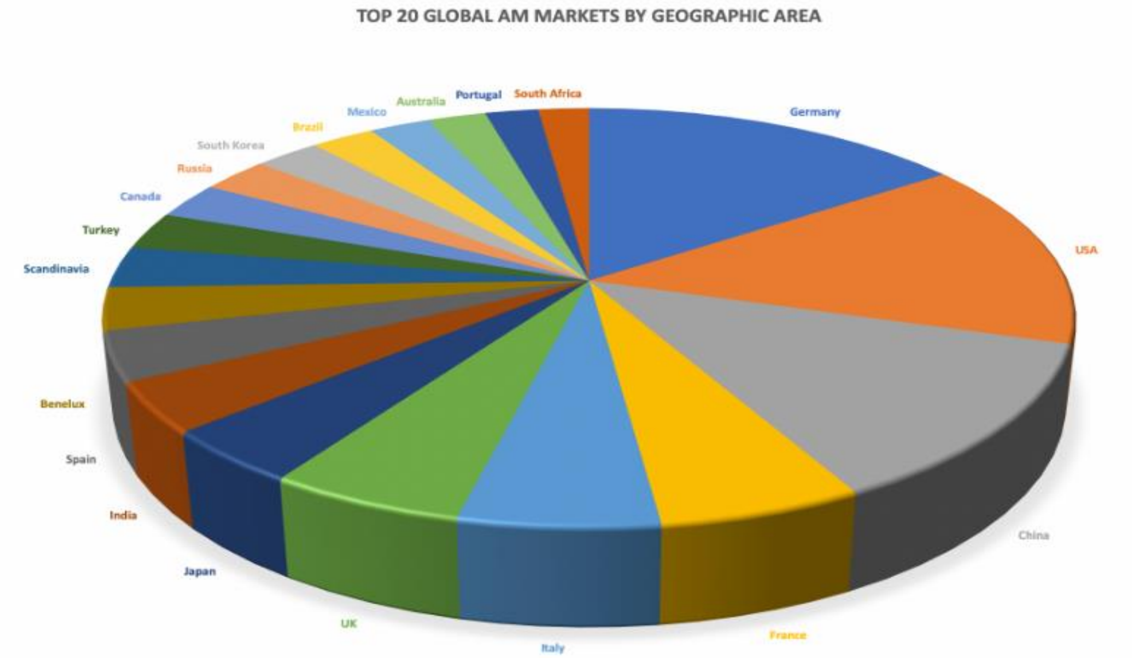
Table 1: Additive Manufacturing Market Growth



Source: Graphic obtained from MakePartsFast, article published by Leslie Langnau in 2020. Data recovered from Smart Tech analysis data in January 2020.

The latest figure shows the top 20 Global AM markets during 2019. The results of this analysis show that Germany is the largest single geographic market, with almost $1.3 billion in yearly revenues, followed by the USA and China. Moreover, 7 of those 20 markets are located in Europe, counting for $3.2 billion, as we can see on figure 2.

Figure 2: The top 20 AM Markets



Source: Article from 3D Printing media published by Davide Sher, information provided from Smart Tech analysis data in January 2020.

In Germany, we find additive manufacturing centres for three of the most important car producers, BMW group, Volkswagen group and Daimler. Moreover, in Europe we also find the AM hub for Jaguar Land Rover in England, the product development centre of excellence in Turin for FCA and the Prototype Development Centre at Seat's factory in Martorell, Spain. On the other hand, in USA we find the 3D Printing hub for PSA, Ford, GM and Renault Mitsubishi.

Despite of this technology's growth, and the importance of the automotive industry at worldwide level, there are no previous articles that assess the impact of the additive manufacturing on the supply chain and logistics of this industry.

At this moment, literature about the implication of AM in the automotive industry is becoming wider and much more advanced now that research institutes of AM are more often colaborating with OEMs.Papers are writting about the advantages and the wide range of potential scenarios for applying additive manufacturing in the Automotive industries (Pune, 2019), other are more accurate and study the statistics impact of AM in the Automotive industry, where are developed theoretical models with a quantitative analysis to analyse the impact of AM on supply chains from a general overview based on the European framework (Delic, Eyers and Mikulic, 2019) or specifically about how

AM can improve the management of spare parts in the Automotive industry (Beiderbeck, Deradjat and Minshall, 2018). Other case studies are more precise and analyse the adoption of additive manufacturing from the engineering approach, studying the applicability of laser sintering (Flores Ituarte, Chekurov et al, 2018) or the applicability of new AM processes and materials for Automotive series part production (Wiese, Thiede and Herrmann, 2020). Also papers are focusing on the tooling approach where a a stamping process is created for the production of body panels for the automotive industry (Leal, Barreiros, Alves et al, 2017), or from the environmental approach since AM is a technology which enables LEAN manufacturing (Böckin and Tillman, 2019).

Comparing the purpose of those papers to the objective of this one, we can say that studies so far have not analysed recent advances by using clear simulations. From one hand, we find papers studying certain technologies and materials from the engineering approach. From the other hand, similar papers as the conducted by Delic, Eyers and Mikulic in 2019 and 2020, are analysing the adoption of AM on the flexibility and performance of automotive supply chains, those are based on surveys and it is used the general data to know how AM impact positevely on the flexibility of supply chains. However, the objetive of this paper is clearly differentiated from the others by focusing on the advances of a particular product developed by 3D printing, describing the production phase of this product by using conventional manufacturing or additive manufacturing, and dismantling suppliers chain from raw material to Tier 1 to know effects on supply chains.

As a logistics and maritime businesses student, it is highly motivating to know what the principles of these new technologies are to find out which purposes are reserved for them and how they can interfere in the manufacturing and distribution framework. The choice of this topic is quite clear, as it is already mentioned the fourth industrial revolution is at the gates to trigger a reshaping of our globalized manufacturing structure and consequently to our Global Supply Chains. In addition, knowing the impact of this new scenario on logistics and how those technologies can be applied to logistics are a duty to understand the future of our sector. Meanwhile this revolution is taking place, many companies have already taken a step forward and have invested on them or simply are testing how to work with them.

2. Theoretical framework

2.1. Context of Additive Manufacturing

¿What is Additive Manufacturing? Additive Manufacturing or AM, also commonly known as 3D Printing or 3DP, is an umbrella concept for many different technologies. AM is divided into subcategories, these subcategories are rapid manufacturing for producing serial parts, rapid prototyping for producing prototypes or models, and rapid tooling for production tools for manufacturing like moulds (Barz, Buer and Haasins, 2016). Mainly, additive manufacturing is referred to the industrial approach and describe the most advanced techniques such as Selective Laser Sintering (SLS) whereas 3D printing is the term preferred from the technology approach and mostly it describes the Fused Deposition Modelling (FDM) or Fused Filament Fabrication (FFF) which are techniques requiring smaller and cheaper equipment comparing to those printers for industrial manufacturing. However, both AM or 3DP are interchangeable since they describe same building processes but there are contexts where one term is more appropriate than the other (Lucie Gaget, 2017). This paper prioritizes the use of AM over 3DP because of analysing the irruption of this technology from an industrial perspective.

According to ASTM/ISO 52900 Standards, the largest international voluntary standards developing organization, there are 7 categories regarding AM processes which are summarized in figure 3:

1. Material extrusion: AM process where the material is selectively dispensed through a nozzle or orifice.

2. Material jetting: AM process where droplets of build materials are selectively deposited.

3. Binder jetting: AM process where a liquid bonding agent is selectively deposited. It is also known by the names inkjet powder printing and 3D printing.

4. Sheet lamination: AM process where sheets of material are bonded to form an object.

5. Vat photopolymerization: AM process were liquid photopolymer in a vat is selectively cured by light-activated polymerization. It is also known as stereolithography (SLA).

6. Powder bed fusion: AM process where thermal energy selectively fuses regions of a powder bed. The first powder bed fusion process invented is known as Selective Laser Sintering (SLS).

7. Directed energy deposition: AM process where focused thermal energy fuses materials by melting as the material is being deposited. There's a wide variety of processes that fall under this category, like directed light fabrication (DLF), direct metal deposition (DMD), and the most popular, laser engineered net shaping (LENS).

The industry itself together with the standards organisations, have categorised AM processes so as to provide a transparent understanding of the different types of technologies in use today (De la Torre, 2014).

3D printers use additive processes, they differ between each other depending on the way layers are built to create the final object. Layers are produced by melting or softening. Commonly, technologies that use this way of 3D printing are Selective Laser Sintering (SLS) and Fused Deposition Modeling (FDM). Referring to SLS, it uses a high-powered laser to fuse small particles of plastic, metal, ceramic or glass powders into a mass that get a desired 3-dimensional shape. Referring to FDM, it uses thermoplastic materials injected through nozzles onto a platform. Finally, it is named Stereolithography (SLA) which use laser technology to deposit layer upon layer of photopolymer resin. (Attaran, 2017). As we can observed in figure 3, 3D printing processes SLS, FDM and SLA belong to the following AM technologies: Powder bed fusion, material extrusion, and VAT photopolymerisation, respectively.

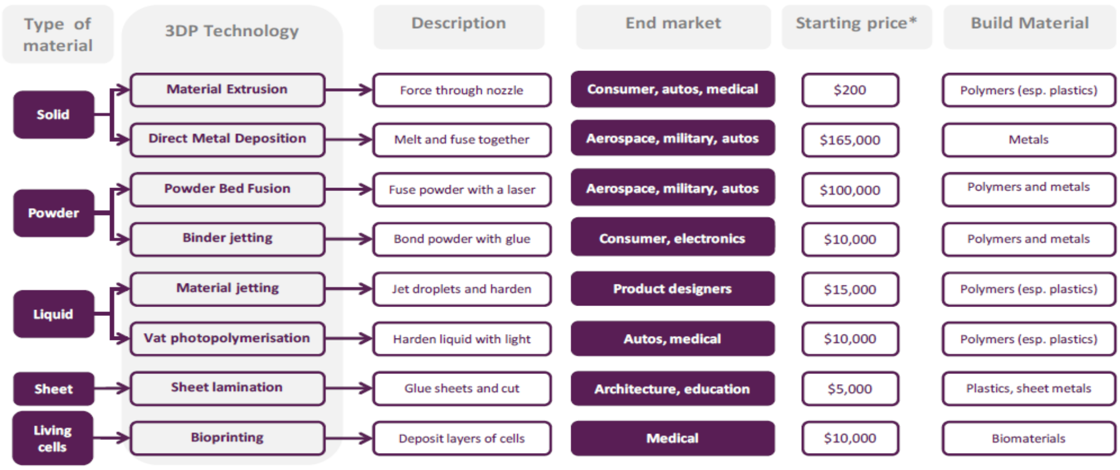
Table 2: Process types of Additive Manufacturing

Process Type	Technique Definition	Example Technology	Material
Vat Photopolymerisation	Liquid photopolymer in a vat is selectively cured by light-activated polymerisation.	Stereo lithography (SLA), digital light processing (DLP)	Polymers and ceramics
Material Jetting	Droplets of build material are selectively deposited.	3D inkjet printing	Polymers and composites
Binder Jetting	Liquid bonding agent is selectively deposited to join powder materials.	3D inkjet printing	Metals, polymers, and ceramics
Material Extrusion	Material is selectively dispensed through a nozzle or orifice.	Fused deposition modelling (FDM)	Polymers
Powder Bed Fusion	Thermal energy selectively fuses regions of a powder bed.	Selective laser sintering (SLS), Selective laser melting (SLM), electron beam melting (EBM)	Metal, polymer, composites and ceramics
Sheet Lamination	A process in which sheets of material are bonded to form an object.	Ultrasonic Consolidation (UC)	Hybrids, metals and ceramics
Directed Energy Deposition	A process that focused thermal energy and fuses materials by melting as the material is being deposited.	Laser metal deposition (LMD)	Metals and hybrid metals

Source: Classification of AM processes from European Comission research on AM in 2014

Type processes of additive manufacturing are commonly titled as 3DP technologies as we can see on table 2. This table offers more information regarding the end market of AM technologies and a guidance price for each one.

Figure 3: The 8 primary technologies within 3D printing industry



Source: Global Data, thematic research called 3D Printing in 2019

Therefore, 3D printing is one of the technologies within the umbrella of AM and Industry 4.0, term adopted later from the high-tech German strategy to transform the conventional manufacturing. But, at the same time, 3DP rather than utilize a single technology, it uses a range of specific techniques appropiate to different printers with different characteristics (Mewawalla, 2019) as we see on the figure. However, all techniques build the object through printing the materials layer by layer adding liquid, sheet, wire or other powdered materials to form component parts or products based on a 3D digital model file (De la Torre, 2014). More than one hundred of raw materials can be used for additive manufacturing. They include thermoplastic plastics, metal, nylon, acrylic, plaster, ceramic, and edible material (Chen, 2016). The inner nature of 3D holds huge potential to disrupt the way in which a product could be designed, developed and manufactured. Moreover, AM allows parts to be designed with more complex architectures and, at the same time, with little additional costs. For example, structures with hollowing, holes, atypical shapes or rich interior details. In addition, “some pieces that used to be molded separately and then assembled can now be produced as one piece in a single run, even for some precision components” (Bonneau, Yi, Probst, Pedersen and Lonkeu, 2017).

Additive manufacturing or 3DP works accordingly to the following basic steps (Lopez Parada, 2018):

1. Creation of 3D model by design software Computer Aided Design or CAD or scanning the item.
2. The CAD file is transformed into a geometric 3D format called Standard Triangle Language or Standard Tesselation Language or STL
3. Transferring the STL file to the 3D Printer and configuring the machine.
4. Manufacturing the item layer by layer
5. Security and cooling period
6. It might also include additional processes as cleaning, polishing, painting etc.

2.2. Types of manufacturing processes on the current production framework

Meanwhile, the conventional manufacturing framework is composed of 3 different processes. We differentiate between:

1. **Subtractive**: Process of taking a blank piece of material and, following a precise serie of programmed instructions, to remove material from the block until just the final product remains. The main manufacturing process is CNC machining.
2. **Forming**: Process which deforms the material to produce the desired shape.
3. **Casting**: Process of heating resin and injecting it at pressure into a mold cavity, which then solidifies and sets, before being ejected. The main manufacturing process is injection moulding.

The main basic approaches mostly used on the current manufacturing are the following ones (Mewawalla, 2019):

- **CNC machining.** Computer Numerical Control or CNC machining describes the process of taking a blank piece of material and, following a precise serie of programmed instructions, to remove material from the block until just the final product remains. In terms of choosing the right process, when the need is for low volumes, CNC machining is the quickest process. When 10 parts are needed in a short term, CNC machining is probably the best choice. If the target is 55000 parts in a long term, injection moulding is the better choice.
- **Injection molding.** It means the process of heating resin and injecting it at pressure into a mold cavity, which then solidifies and sets, before being ejected. Injection moulding requires time to make the mold and ensure the parts are in tolerance. This takes from a few weeks to a few months. Once this is finished,

creating parts using the mold is a very fast process. The upfront time investment of injection molding pays off at high volumes.

The irruption of AM didn't come up to completely replace existing conventional subtractive production methods. However, "it is expected to revolutionize many niche areas. Exponential growth is expected to be on the horizon. Savings in cost and speed have been predicted" (Attaran, 2017). Also, as it is said by GlobalData's research, it will not replace traditional manufacturing technologies, such as CNC machining (in which pre-programmed computer software dictates the movement of factory tools and machinery) or injection molding (in which parts are produced by injecting molten material into a mold). However, "it will work alongside them to create a digital manufacturing ecosystem" (Mewawalla, 2019).

Table 3: Type of processes of Subtractive manufacturing

PROCESS	MATERIALS
CNC machining (turning, drilling, boring, milling, reaming)	Hard thermoplastics, thermoset plastics, soft metals, hard metals (industrial machines)
Electrical discharge machining (EDM)	Hard metals
Laser cutting	Thermoplastics, wood, acrylic, fabrics, metals (industrial machines)
Water jet cutting	Plastics, hard and soft metals, stone, glass, composites

Source: Formlabs, 3D north American printer maker

And now with the irruption of Additive manufacturing, the current manufacturing framework is composed of 4 different ways of production. If we compare this new technology with the traditional manufacturing, the result obtained is a deep change on the production's meaning. We come from cutting or moulding shapes, reducing or removing materials to combine raw materials in a precise, flexible and sustainable way. It uses the necessary material to manufacture, avoiding any kind of waste, heading the production closer to the Lean philosophy. Mainly, the advantage of 3DP compared to the other manufacturing methods is that 3D printing eliminates many of the assembly steps required during the production phase in the supply chain and it just need a single task; therefore, process complexity is reduced, making the material flow more transparent and easier to control (Janssen, Blankers, Moolenburgh and Posthumus, 2014).

The capabilities of this new technology offer several advantages:

- Increase of design capabilities. The assembly can be done by a single process.
- Tools are not required.
- Decentralized manufacturing. Production can be done at any place. The files can be sent to be manufactured close to the consumer, reducing the need of transport.
- High customization.
- Use of material efficiently.
- Reducing lead time.
- Reducing transport costs.
- Sustainable technology.
- Availability of products.
- Reducing design cycles; shorter time to market.
- Reduced weight.

However, 3D printing also represents some constraints:

- The size of products depends on the printer dimensions.
- Small batch production series
- Limited choices for materials, colours, and surfaces
- Limited strength and resistance to heat, motions and colour stability

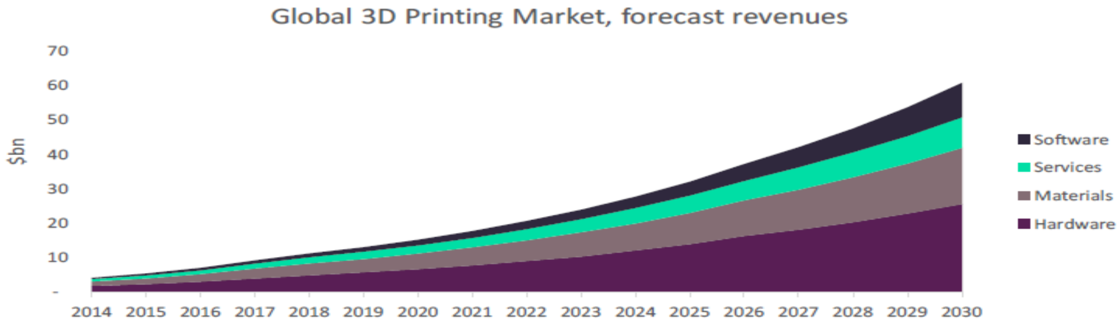
2.3. Market size and players of Additive Manufacturing

According to GlobalData and its thematic research on 3D Printing, the AM's market breaks down into 4 segments:

- **Hardware**: Refers to the machines that actually do the work of the additive processes to make physical things.
- **Software**: Refers to the programs that convert design data into fabrication data, as well as the software onboard the machines and the software that routes data to the machines. This includes CAD software, slicing software and programs designed to track the flow of the 3D printing process, such as digital twins.
- **Materials**: Refers to the printing supplies of specialized polymers, ceramics, and metal alloys, supplied in powder form, which are the building bricks of 3D printing, as well as any consumables required for specific processes

- **Services**: Includes a range of consulting services, comprising design and both production and factory management. It also includes repair services.

Figure 4: Market size of 3D Printing

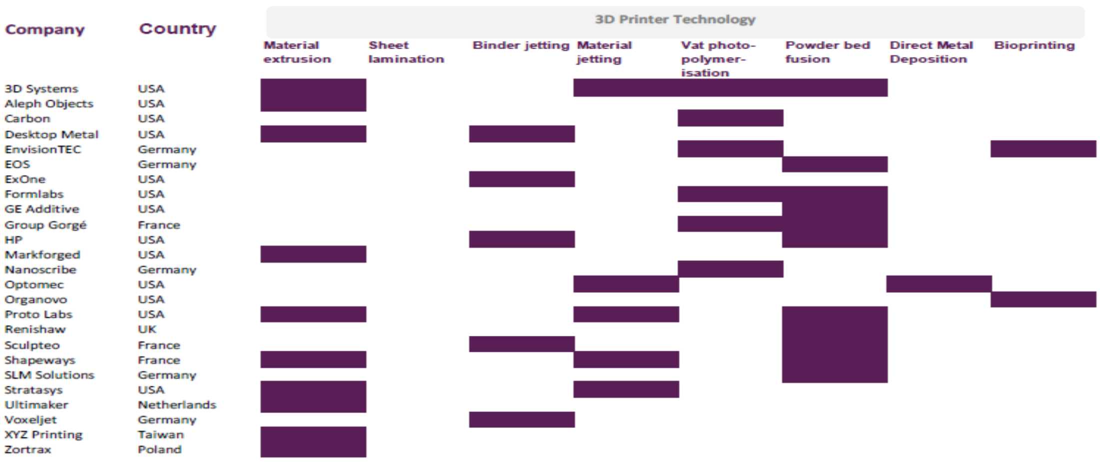


Source: Global Data, thematic research called 3D Printing in 2019

According to the paper and as we can see on figure 4, the market accounted for just over $11bn in spend in 2018 (when sales of 3D printing hardware, software, materials and services are included) is set to be over $13bn by the end of 2019, rising to $32bn by 2025, and over $60bn by 2030.

Furthermore, this paper continues assuming that the steady compound annual growth will increase of around 16% in hardware, materials, and services and around 20% in software from 2018 to 2025, when growth rates will start to flatten. By 2030, when the 3D printing industry will have matured, growth rates on hardware, materials and services will drop to around 12% when 3D printing revenues will exceed $60bn. Software growth rates will remain high at around 20%.

Figure 5: Market players of 3D Printing

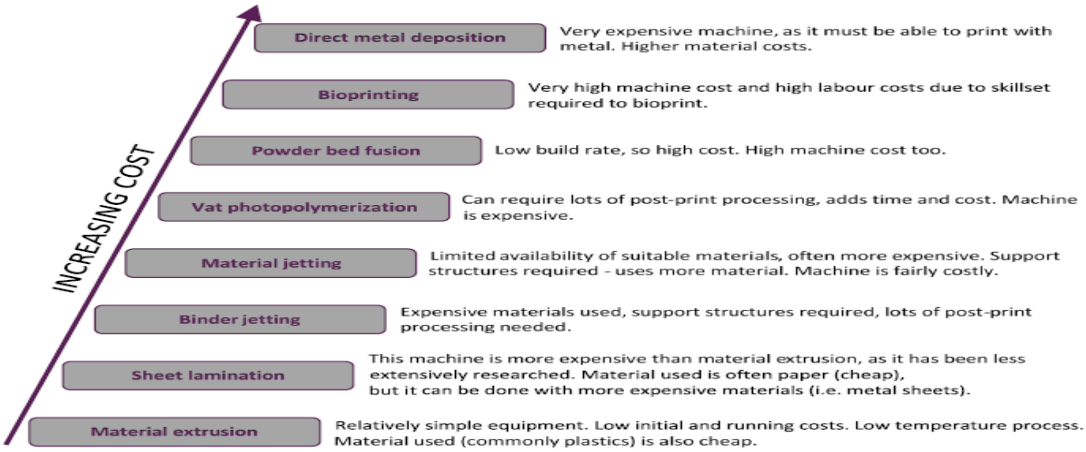


Source: Global Data, thematic research called 3D Printing in 2019

Figure 5 reveals that most of the 3D Printer makers are located in US and Europe, this piece of information confirms the assumption of the potential shift of production's decentralization from Asia to Europe and US and the high investments on the Industry 4.0 in Europe.

The cost of the different 3DP techniques varies depending on the complexity of the printer and the material used. It ranges from the lower costs of materials extrusion to the very expensive costs of direct metal deposition. The process choice mainly depends on the final purpose, the required quality of the finished product, the duration of the process, and the overall cost picture (Mewawalla, 2019).

Figure 6: Ranking of cost of 3D printing processes



Source: Global Data, thematic research called 3D Printing in 2019

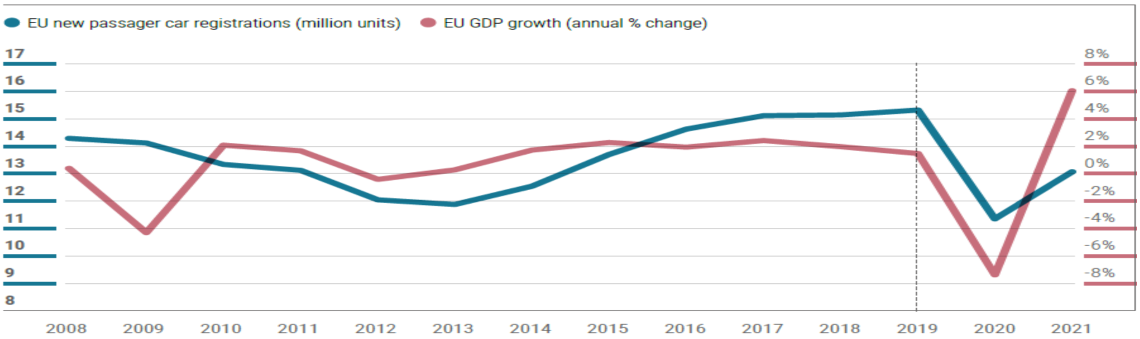
2.4. The Power of the automotive industry on global economy

Every year the European Automobile Manufacturers Association (ACEA) releases a report related to the latest figures and data in the EU auto industry. According to the last report of 2020-2021 called the "The Automobile Industry Pocket Guide", the automotive sector represents the 7% of the EU's total GDP thanks to its annual turnover. The employment figures places in 14.6 million Europeans, the amount of employed people working directly and indirectly in the auto industry, it accounts for 6.7% of all EU jobs and 11.5% of EU manufacturing jobs. Vehicle manufacturing is a powerful and strategic industry in the EU, where 18.5 million cars, vans, trucks and buses are being manufactured every year and where taxations generate a high fiscal income from motor vehicles, in 2019 €440.4billion.

Auto makers or automobile manufacturers are operating around 226 vehicles assembly and production plants in the European Union. Moreover, the automotive sector is the EU's number one investor in R&D, responsible for 29% of total spending. Data says that the investment in R&D in the EU's automotive industry has increased by 6.1% to reach €60.9 billion annually.

The trade's balance is quite positive, we are talking about €135.9 billion of motor vehicle exports whereas imports are sized in €62.0 billion motor vehicles.

Figure 7: Comparison of EU new passenger car registrations and EU annual GDP growth



Source: ACEA Pocket guide 2020-2021

From the above figure comparing the new passenger car registrations in EU to the EU GDP growth, we can see that changes on new passenger car registrations are impacting directly to the GDP growth, it is holding up GDP growth when there is an annual growth's drop as we can see during 2008 crisis and also it is also significant when new passenger car registrations from 2011 to 2013 experienced a rapid fall, the GDP growth fall at a fast pace as well.

2.5. Role of Additive Manufacturing in the Automotive industry

As we can read from specialized newspapers in additive manufacturing like 3D Printing media network (3dpbm) who has recently published an e-book specially focus on the Automotive market called "Automotive AM", there are currently a broad amount of vehicle manufacturers being interested in how additive manufacturing can improve their production, how it shortens product development and how it allows them to offer high customitzation value-added services to their customers.

Once we have read paper related to this topic, we define the adoption of AM from diferent perspectives. Thus, the role of AM can be spread out into different applications. One of these applications is related to custom trim body components, including bumpers and fenders. BMW Group has already done further steps on this approach, they developed the project of "Mini Yours Customised program" where customers were allowed to design some exterior and interior components for some MINI car models. The product range included the indicator inlays known as side scuttles, trims for the passenger side in the interior, LED door sills and LED door projectors. Customers were able to select between different colours, patterns, surface finishes and icons for designing. Then, it allowed also integrating their own texts and their signature into the design (Press BMW Group)

Figure 8: 3D printed side scuttle

Source: BMW group website. 3D printed piece by using MINI Yours Customized program.

Figure 9: 3D printed trim for the passenger side

Source: BMW group website. 3D printed piece by using MINI Yours Customized program.

Figure 10: 3D printed LED door sill

Source: BMW group website. 3D printed piece by using MINI Yours Customized program.

Figure 11: 3D printed LED door projector

This application is also being used by the automaker PSA group comprised by brands like Peugeot, Citroën and DS who is using AM for the mass customization of body interior features for the special edition DS3 Dark Side.

Figure 12: Titanium features of 3D printed interior

Source: Article published in 3D Printing media by Davide Sher, January 20th, 2020. https://www.3dprintingmedia.network/psa-additive-manufacturing/

Another company is Daihatsu Motor Company, a Japanese automaker, which allows buyer to order 3D-printed "skins" for the front and rear bumpers of Daihatsu's Copen 2-door convertible. The material used for the effect Skins is Acrylonitrile Styrene Acrylate or ASA thermoplastic, which is durable and enables thin, sturdy walls. This new technique offers the buyers to choose from 10 colours and 15 base patterns. As Daihatsu indicates, the results obtained by using this technology is the short production time, a customised car that might have taken two months under traditional techniques will be delivered in two weeks with the 3D-printed parts (Pearson, 2020).

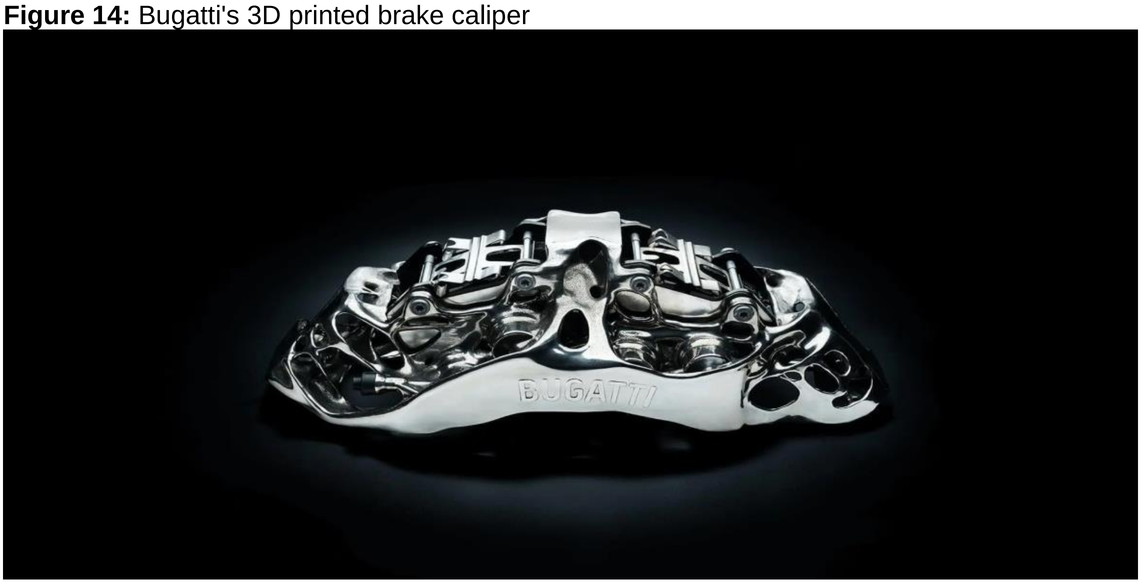
Figure 13: Customized 3D Printed skin for exterior's body

Source: Stratasys website, article from A. Pearson in March 2020. The picture shows a certain effect skin for the exterior car's body.

The second application is rapid manufacturing, AM is also present in producing several powertrain and chassis parts. The car maker Bugatti has created the revolutionary titanium 3D printed brake calipers.

The development carried out by Bugatti, member of the Volkswagen Group, is its most relevant printed part so far because of its functionality. The company developed the first brake caliper made by AM. The advantages of producing it by AM are the weight reduction and it gains more robustness. It is assembled in models such as Bugatti Chiron.

Figure 14: Bugatti's 3D printed brake caliper



Source: Article published in 3D printing Media Network by Davide Sher, 2020. https://www.3dprintingmedia.network/volkswagen-additive-manufacturing/

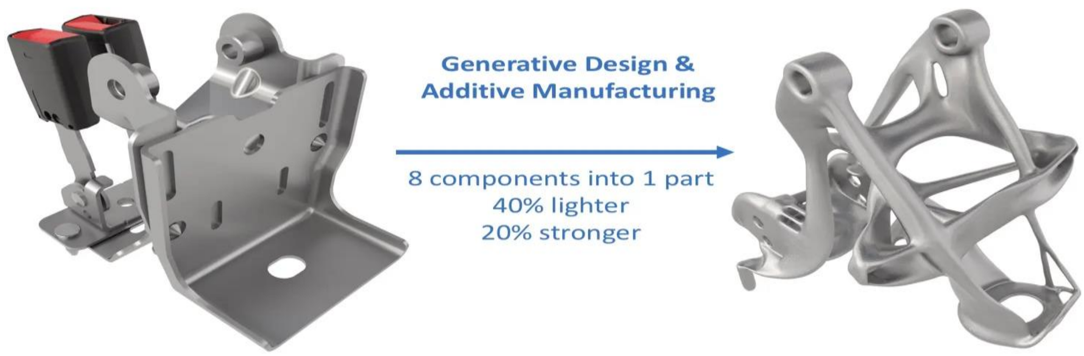
Audi is also using 3D printing for replacement parts that are not commonly needed, such as water connecting pipes for the W12 engine, the metal is the material used for these parts (Sher, 2020).

***Figure 15**: Metal 3D printed water connectors for the Audi W12 engine*

Source: Article published by Davide Sher in 3D Printing Media Network, 2020. https://www.3dprintingmedia.network/volkswagen-additive-manufacturing/

Another major field for rapid manufacturing is body interior parts. The following case is General Motors. The firm produced a very useful and valuable part, a generatively designed seat bracket. This component requires about eight separate parts from different automotive supplier. This bracket is 40% lighter and 20% stronger than the standard part.

Figure 16: 3D Printed seat bracket



Source: Article published on 3D Printing Media Network by Davide Sher, January 6th, 2020. https://www.3dprintingmedia.network/general-motors-additive-manufacturing/

Rolls Royce, the luxury brand of BMW group, is also adopting AM for manufacturing body interior parts. The components below are parts already produced using additive manufacturing for the Rolls-Royce Phantom's model (Sher, 2020):

- High-visibility plastic holders for hazard-warning lights,
- Center lock buttons,
- Electronic parking brakes,
- Sockets for the Rolls-Royce Phantom,
- Mounting brackets for fiber-optic cables.

The third application is prototyping, the most extended application along the OEM's. Porsche, the german auto manufacturer specialized in sports cars, has revealed a project to manufacture a complete housing for an electric drive using AM. The 3D printed E-Drive housing on the engine-gearbox unit was produced using additive laser fusion. According to Porsche's media, the weight was reduced up to 40%, the integration of parts makes the housing even more compact and reduced the assembly work by 40 work steps, translating to time this process saves 20 minutes. But the major benefit of integration was the improving of cooling.

Figure 17: 3D printed E-Drive housing

Source: Porsche's official website (https://newsroom.porsche.com/en/2020/innovation/porsche-protoype-small-production-electric-drive-housing-3d-printer-23235.html)

Another remarkable case is the collaboration of Fiat Chrysler Automobiles (FCA) and Fraunhofer, a research institution of AM, manufacturing the entire suspension system which later might be implemented into series production. Suspension systems are formed of different critical components which need to be assembled. The suspension system printed by FCA was originally composed of 12 components but printed in just one piece and the weight was reduced up to 36%. It integrates wheel carrier with brake caliper.

Figure 18: 3D printed suspension system

Source: Fraunhofer official website (https://www.iapt.fraunhofer.de/en/press-media/Press_releases/Press_Release_Fiat_Chrysler.html)

The fourth application of AM is rapid tooling. As we observed, a company called Sand 3DP is now integrated into BMW to collaborate in the manufacturing side, they produce moulds and cores that are later on used to cast. The main approach of Sand 3DP is the tool manufacturing, they are printing many jigs and fixtures with an FDM printer. This way, BMW uses 3DP to complement traditional manufacturing technologies (Rehnberg and Ponte, 2018). Moreover, BMW is also printing handheld tools that are used to attach bumpers and license plates (Bogue, 2013).

As we have already mentioned before, General Motors (GM) has introduced AM into their production basis. In addition to this rapid manufacturing AM's introduction, GM has aslo developed 3D printed tools. An example revealed by 3D Printing Media Network is a tool used to align engine and transmission vehicle identification numbers which can cost less than $3 to make using a thermoplastic extrusion 3D printing technology. If this same piece were outsourced, the part would cost $3,000.

Ford has been long using 3D printing to manufacture assembly tools, these are hand tools like fixture and jigs. Now the design process lasts 20 minutes allowing them to start producing quickly in case of peak demands under low costs and high accuracy.

Figure 19: 3D printed labeling jig

Source: Specialized 3d printing's newspaper called 3dprint (https://3dprint.com/229544/ford-trinckle-automate-design-of-3d-printed-production-tools/)

2.6. Conclusions of theoretical framework

As we have been explaining before, the future role of additive manufacturing in the automotive industry might be very extensive and highly functional. AM's market itself is growing at a rapid pace, 3D printing processes are getting more matured, there are coming up new materials and the interests and investments in this technology are more often present along the industries. For example, in 2020 General Motors announced its new Additive industrialization center in Detroit to push 3D printing forward and BMW Group announced its Additive Manufacturing Campus same year as well. A few years ago, Ford also opened its Advanced Manufacturing center in 2018 and endless number of automotive players are using 3D printing at their facilities from large automakers to Tier 1 suppliers.

This technology is becoming increasingly disruptive, the wide range of AM processes and technologies and the increasingly number additive players supporting and collaborating OEM's to adopt 3D printing at their facilities is quite popular. The results are very positive in terms of flexibility, cost and time. As we have already mentioned, the components being printed are limitless, even there are projects where the whole car is being printed. Components can be printed in just 20 minutes and in site, this is so revolutionary if we compare it with latest production's method when it required the producing of a mold and injection and where the mold was produced at off-site facilities.

Moreover, literature related to this topic is wide but there is not any paper studying about any real case resulted from the collaboration of technological institutes with car makers. We can find some where authors have studied the impact from a quantifying model but simply considering the amount of OEMs who owns 3D printers at their facilities but not taking into consideration the purpose of using them and the analysis is conducted from a general overview. We have found a gap on the literature and we pretend to deeply study the adoption of AM from a concrete and contextualized point of view. For that reason, we use the collaboration between FCA and Fraunhofer related to figure 18 as a reference for the following analysis. It belongs to the application of prototyping and we strongly believe that this disruption may trigger the adoption of additive manufacturing on series production. For that reason, this thesis pretends to integrate this innovation into an actual scenario and analyse effects on supply chains and intermediaries.

3. Objectives

Literature about 3D Printing's disruption predicts deep changes on the current layout of Global Supply Chains, revealing great consequences for the manufacturing and transport current structure and foreseeing future drops on shipping because of the decentralized manufacturing driven by Additive Manufacturing. Many authors are describing the potential application's role of 3DP on the management of spare parts and obsolete materials (López Parada, Khajavi, Holmström and Partanen….) and the opening of new business models closer to the consumer markets in contrast to the declining of shipping needs (Chen, Rehnberg and Ponte, Mewawalla, Janssen, Sher, Mhor and Khan…) as it is summarized by Attaran, AM technologies can impact on supply chains in many different ways, including accelerated product development, reduced economical batch size, increased production flexibility, and reduced material waste.. However, most of the authors agree that traditional manufacturing and these new technologies must coexist for being able to offer several advantages.

We found out a gap on literature and we pretend to fill it out. The differentiating key point of this paper lays on focusing on a particular and recent development and drawing a new paradigm around it.

Therefore, the purposes of this thesis lay on bringing insights on the potential applications of 3D Printing in the automotive industry in order to understand how these technologies can shape the structure of supply chains by applying the features of AM on real scenarios. It should be noted that this thesis is closely connected to the automotive industry to delimit the boundaries of this research, the reasons of this clear delimitation choice are because of the worldwide importance and presence of this industry and the proximity of tutor's and student's knowledge to this sector. Scientific research question and the investigation methodology are exposed below.

Question research line: If additive manufacturing is adopted by the car manufacturers to produce the chosen object of study instead of using conventional manufacturing, which could be the impact on supply chains? Can we expect effects on shipping and transport demands?

- **Objectives of research** (objectives are related to the selected object of analysing):

- ✓ Comparing conventional manufacturing and AM by describing the production steps
- ✓ Identifying suppliers along the chain from raw material to Tier 1
- ✓ Analysing the effects on future supply chains whether the OEM decides to use AM instead of conventional manufacturing
- ✓ Calculating potential impacts on the supply chain

The background from above objectives is collected from real cases where companies as Original Equipment Manufacturers, also known as OEMs, or car part suppliers are using additive manufacturing in some of their processes, improvements observed must be compared to traditional processes and understanding how those applications are shaping the supply chains. The purpose is collecting that valuable information based on real projects and create potential scenarios where those progresses configure a new paradigm on global trade.

4. Methodology and data

How do we stablish the guidelines for studying the object of anaylisng?

First of all, **why have we chosen this case**? We have chosen the remarkable collaboration between the OEM Fiat Chrysler Automobiles (FCA) and Fraunhofer Research Institution for Additive Manufacturing Technologies IAPT. The main reason is related to the relevance of this progress. This development is considered as an ambitious project because we are talking about a system which consists of various individual parts from the brake system and suspension system. By Printing, the part is manufactured in just one step even though it still contains individual components. Originally, these components are manufactured individually and then assembled in several steps using screws, seals, and washers. Besides, it is a 3D printed prototype but according to the words from both companies, the idea is implanting it for series production.

The results are that the prototype weights 36% less than by the conventional manufacturing, it reduces costs and the assembly efforts enormously, and shortens the lead time.

This kind of developments approach the idea of implementing additive manufacturing into series production. For that reason, we aim to recreate a simulation where a hypothetical scenario maps the susceptible affected supply chain. It should be noted that the information regarding supply chains and suppliers related to this thesis development is not officially released by FCA and we want to emphasize that additive manufacturing is not currently being used for series production in the automotive industry, but it is closer than ever.

Analysis of data

The methodology consists of 3 different steps:

i. Comparing both production models for the same developed parts and analysing differences.
ii. Planning a simulation where additive manufacturing is used for the productions of these kind of pieces.
    a. Introducing main information regarding intermediaries, locations, distances, modes of transport, shipping routes, frequency and batch’s size.

b. Mapping the global supply chain, locating suppliers behind the conventional production of these car pieces to find out a potential impact on SC.
c. Introducing the criteria and core data for making the calculation.

iii. Calculating the impact based on the criteria.

Sources of data

According to the data used for this analysis, basic information regarding the object of study is provided by media specialized in 3d printing as 3D printing media network and the press release from Fraunhofer institute where the benefits of applying 3D printing were described and we got a first contact with them via e-mail to obtain more specific information related to the actual printed pieces.

According to step 1, process comparison between SLM and cast moulding, where we compare both manufacturing methods, we have focused on understanding how is currently produced the brake caliper to understand how many components are required. For this part, we have collected information regarding the production of brake calipers from specialized braking suppliers like BCC Brakes and suspensions and ZF TRW. Regarding production's time, we have been in contact with Eurecat, technological centre of Catalonia, to receive some insight about SLM and regarding cast moulding, we approached Teksid via e-mai. Teksid is the manufacturer of brake caliper bodies and steering knuckles.

According to step 2, we introduce the background for doing the simulation and calculating the potential impact of additive manufacturing on supply chains. The context is divided in three questions in order to explain the sources of the simulation:

a) How do we set up the scenario of simulation? Information is provided by internal sources from my company because we are suppliers of FCA Tychy, and CEVA logistics, which is the logistics provider of FCA Tychy. Information regarding their suppliers is obtained directly from them via e-mail or their websites, Brembo and Teksid.
b) How do we map the scenario of simulation? Information provided by CEVA logistics and supply chain structure is the mainly used in the automotive industry, we adopt the pattern used in my company.

c) How do we calculate the scenario of simulation? Information provided by CEVA logistics and from the Seaports Authority of Szczecin and Swinoujscie.

According to step 3, we carry out the calculation with an excel file. We calculate the impact simulating that 3D printing is applied on the most sold FIAT's car in 2020, Fiat 500. The simulation takes places in the manufacturing site of FCA Tychy in Poland and the main suppliers already identified are Brembo Poland Sp. z o.o. and TEKSID IRON Poland Sp. z o.o, supplier of brake calipers and steering knuckles respectively.

Figure 20: 3D printed piece object of study

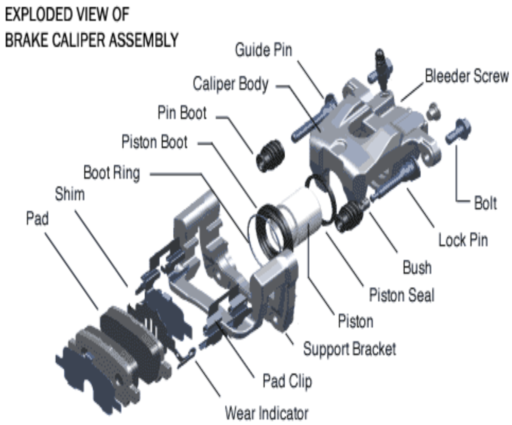
Source: Press release from Fraunhofer Institute IAPT (https://www.iapt.fraunhofer.de/en/press-media/Press_releases/Press_Release_Fiat_Chrysler.html)

5. Analysis and results

5.1. Process comparison between SLM and cast moulding

Nodular iron casting moulding process:

1. Iron is melted in the furnace.
2. Liquid iron is poured into a mold cavity.
3. Waiting time for cooling and solidifying to obtain the part.
4. Mold removal and ejection of part from mould cavity.
5. Cleaning.
6. Trimming.
7. Inspection.
8. Assembly (case of calipers).



The additional process of brake calipers assembly is composed of around 10 components.

Process steps for SLM:

1. Pre-processing, reaching the optimal material's temperature.
2. Laser melts the powder bed layer by layer (48h).
3. Once the object is built, time for cooling (12h-24h).
4. Cleaning parts.
5. Removing the suports.
6. Post-processing. For example, trimming.

The conventional manufacturing process, cast moulding, has the advantage of being a moulding line, this means that the production is non-stop during the daily production shift and the output resulted is large batches during a certain unit of time. The production's time is around 25 minutes to obtain an ejected part from the mould cavity, after cooling and before trimming and the corresponding inspection. Either the steering knuckle or the brake caliper are iron casted at Teksid foundries, the latter after casting needs to be transported to Brembo where will be assembled, the assembly could take around 15 minutes per part. According to SLM, the additive manufacturing process, the time for printing and cooling is much longer than mould casting. The current properties of SLM are not advanced enough to be applied for series production. At this time, their main applications are rapid prototyping and high customization. Moreover, manufacturing is much costly than cast moulding.

5.2. Simulation

Nowadays conventional manufacturing performs greater operational capabilities than additive manufacturing when we talk about the serial and mass production that is required for the automotive industry. This industry is characterized by a low-cost production, tight timing for supplying parts to OEM's and a continuous delivery plan of big volumes. For these reasons, the current technology of SLM, which needs long lead times for manufacturing a single unit, cannot support the forecasted quantities from automakers. Despite the current constraints from additive manufacturing, these technologies are improving at a rapid fast pace, and it is of great interest to calculate the effects on the current supply chain's scenario.

The simulation pretends to give answers to the topic of this thesis based on the economic and time feasibility of additive manufacturing in front of conventional manufacturing, assuming that SLM is as capable as cast moulding. Therefore, the study of how additive manufacturing is shaping global supply chains requires to set up the current sourcing chains related to the defined object and set the appropriate scenario in terms of intermediaries involved, locations, distances, modes of transport, shipping routes, frequency and batch 'size.

Results must reflect the trade and the transport needs which could be affected if additive manufacturing were used instead of conventional manufacturing. In other words, how new technologies could impact on the shipping demand.

5.2.1. How do we set up the scenario of simulation?

The scenario is divided into the following inputs.

a. Intermediaries and locations

FCA
FIAT CHRYSLER AUTOMOBILES

The collaboration between Fiat Chrysler Automobiles and Fraunhofer institute gives us the first actor in this supply chain, Fiat as the OEM and final customer from this sourcing chain. In order to define the scope, we are going to focus on a single Fiat's family model, model 500 which involves Fiat 500 and Abarth 500, which is the best-seller from Fiat and the most produced car from the company, counting for 2,5 milions in March 2021. The manufacturing site of Fiat 500 is Thychy, Poland.

The automotive supply chains works in a JIT method with their core suppliers, those are located in a close proximity because the takt time is tight and the lead time must be shortened.

These suppliers are known as Tier 1 and their manufacturing sites are in Poland as well. According to the Group FCA in Poland, under the Group's umbrella, there are different polish companies like TEKSID IRON Poland Sp. Zoo, which is an important foundry's company for metallurgical components for the automakers. Thus, in Teksid Poland is produced the steering knuckle and the caliper for the brake's supplier.

According to the manufacturing site of brake calipers, an important supplier of braking systems for automotive industry, called Brembo S.p.A, has its polish plant at 37 km from Tychy's site. As we have already seen, the production of brake caliper requieres a series of components which often are provided from manufacturing sites located closed to the raw material allocations. The caliper bodies are supplied by Teksid.

Those components (seals, pistons, slide pins, locking bolts, dust boots and brake mounting clips) are made of rubber, aluminium and metal. Moreover, the caliper bodies and the steering knuckles produced at the foundry of Teksid are made of iron. These raw materials are often sourced from China, either those components.

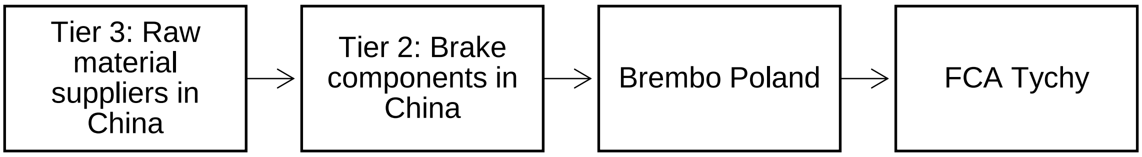
b. Distances, mode of transport and shipping routes

Based on the sourcing structure of automotive's supply chain, Tier 1s are local or very close suppliers from OEMs and from Tier 2s to raw materials suppliers might be longer distances.

In this simulation, we know that Teksid and Brembo are at 37 km and 59 km respectively and the location of Tier 2 and raw material supliers is overseas, counting for days of travelling.

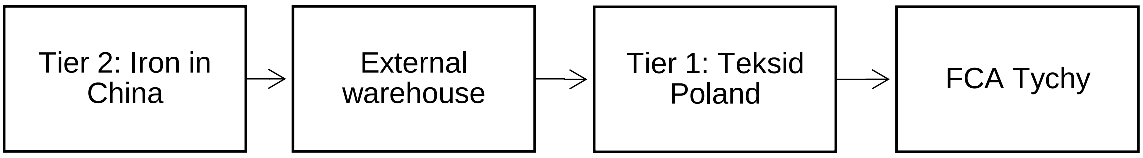
In the simulation's framework we can find three different supply chains involved:

Figure 21: Supply chain 1: Semi-manufactured materials to Brembo



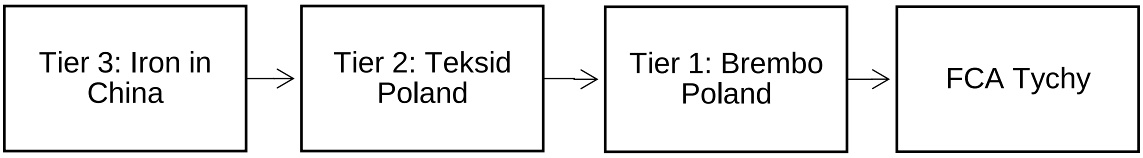
Source: Sequence flow, not external source.

Figure 22: Supply Chain 2: Raw material to Teksid



Source: Sequence flow, not external source.

Figure 23: Supply chain 3: Semi-manufactured calipers to Brembo



Source: Sequence flow, not external source.

- **Supply chain 1**: The assembly of brake calipers requieres multiple components, these come from China and are made of aluminium, metal and rubber. Therefore, in origin we differenciate between the supplier who provide the semi-manufactured components and the various suppliers who provide the raw material. These components are shipped by sea from Shanghai to Hamburg or Szczecin, a commercial port in Poland. Afterwards the container is transport by truck to Brembo's warehouse where the calipers are assembled and delivered to FCA Tychy
- **Supply chain 2**: The manufacturing of calipers bodies and steering knuckles are made of iron which is sourced from the west of China. The mining point is connected to the port by rail and then are stowed in holds and transported by a bulk carrier. The inbound port is Swinoujscie, polish port closed to Szczenin specialized in dry cargo, and where the iron ore is stored in silos. From the storage silos to customers, the transport is done by rail to the 3PL where is managed the reception of materials and smoothly supplies the material to Teksid who is in a very short distance where the material is mould casted and finally delivered to the OEM, FCA Tychy.
- **Supply chain 3**: This chain represents the connection between the foundry of iron in Teksid and the Tier 1, Brembo. The supply is done by semi-trailers every month.

c. Frequency and batch' size

The batch' size and purchase order's frequency estimated is as follows (only is simulated the transport of requirements at destination, the frequency and quantities from raw material supplier to their manufacturers in China are not considered):

- **From Tier 1 to OEM**: Car manufacturers quite often works in FCA conditions, they manage the transport and collection following the milk run method. From the supplier's view, it is an LTL and the material collected could cover one or two production days.
- **Raw material to Teksid**: Considering the high volumes that are moved by a bulk carrier, just a single hold can cover the annual conception for both products. Iron ore is stored at port and every 5 weeks an amount of 20 rail wagons are received in Teksid.
- **Components to Brembo**: 20ft container every 5 weeks.

- **Calipers bodies from Teksid to Brembo**: FTL in a monthly basis.

5.2.2. How do we map the scenario of simulation?

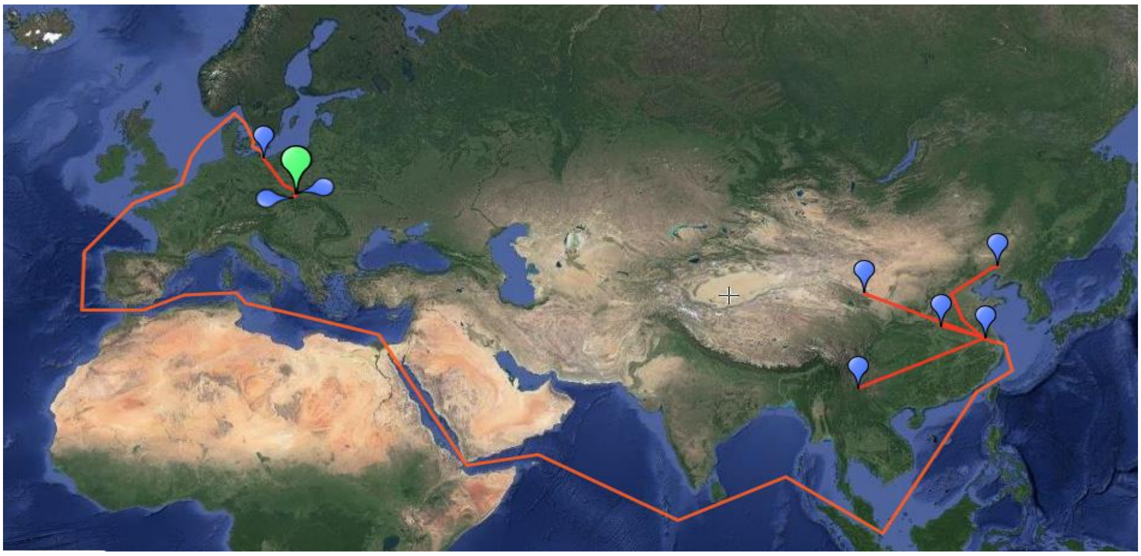
For the simulation, we can assume the following supply chains:

Figure 24: Shipping route from Shanghai to Hamburg

Source: Created with https://www.scribblemaps.com/

This supply chain simulates the sourcing of components or raw material. Chinese brake parts manufacturers are located close to port. However, iron, rubber and aluminium are allocated in different parts of China.

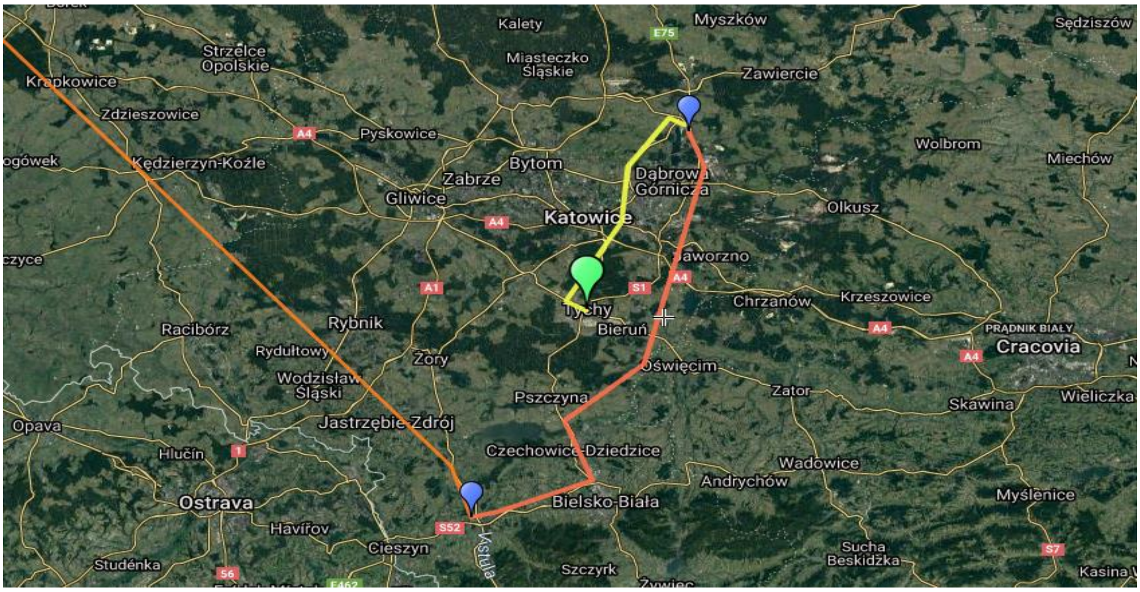
Figure 25: Shipping route from Shanghai to Swinoujscie or Szczecin



Source: Created with https://www.scribblemaps.com/

In this case, the inbound port is in Poland instead of Germany. The inbound port with container terminals is called Szczecin and the port specialized in dry cargo is Swinoujscie, both are located close to the other.

Figure 26: Route map for supply of semi-manufactured calipers from Teksid to Brembo



Source: Created with https://www.scribblemaps.com/

This road route connects the source of iron from port to the external warehouse. The external warehouse distributes the raw material to Teksid (blue point linking orange lane with blue mark) according to the delivery plan agreed. Once the monthly volumes are produced, the amount of calipers bodies are supplied to Brembo (red lane linking blue mark in the south with blue mark in the north). The yellow lane indicated the pick-up from FCA Tychy to Brembo.

5.2.3. How do we calculate the scenario of simulation?

The simulation pretends to calculate the demand for shipping, transport, and warehousing. It simulates a production’s plan together with a delivery plan for the inbound and outbound volumes from a weekly perspective.

The production’s plan differentiates between the production at FCA Tychy and the production in Teksid and Brembo. Both suppliers plan their activities according to the weekly demand from customer.

The core data used for this simulation is:

Table 4: Basic data for the calculation

48	Annual production weeks
5	Production days
800	daily production
10	components by brake caliper
3	Brake caliper (kg)
4.2	Steering Knuckle
38	dias de stock (Week 0 - China imports)
20	Stock in days for inbound quantities + buffer stock of calipers at Brembo
4	Steering Knuckle by vehicle
4	brake caliper by vehicle

Source: Own creation, table sourced from calculation's excel file

The calculation's lay out is split into 4 main criteria and the calculation's table is below:

a. Stock volumes in kg and units
b. Inbound quantities
c. Consumption quantities
d. Transport demand

The calculation is based on the **weekly production** of cars (Fiat 500) in Tychy every week and the corresponding **weekly demand**, in other words, necessary requirements from Brembo and Teksid for covering the weekly production from FCA Tychy.

In order to be adjusted to the reality, it is considered a **week 0,** it contains the safety stock + stock for covering demand until the first provisions.

Stocks are being reduced smoothly over the weeks according to the weekly **consumption quantities** and are being increased according to the **inbound quantities**.

5.3. Results

The goal of this thesis pretends to quantify potential impacts of additive manufacturing on current supply chains. For that reason, we decided to map all the intermediaries for a specific supply chain of brake calipers and steering knuckles required to produce a specific car, Fiat 500, for one year.

Our observations are based on a simulation of the material flow from the supply to the consumption and it is based on the following assumptions:

- Annual production of 48 weeks without considering summer and Christmas shutdowns.

- Daily production of two shifts. FCA Tychy also could work with three shifts and the daily production would be up to 900 cars per day.
- Weekly production of 5 days. OEMs used to plan work for weekends as well.
- Regular production and regular consumption. No variations in demand and no variations in the production's rate.
- Not considered the material flow in China from suppliers to manufacturers and from suppliers to port.

Therefore, taking into consideration the assumptions exposed above, the simulation performed gives us the following annual demand for shipping and logistics, demand that could be impacted by the irruption of additive manufacturing on the current production's framework. The calculation below shows the quantified results:

Table 5: Calculation's lay out

	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Weekly production		4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
weekly demand		32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000
Stocks											
Raw material at Tecksid (kg)	875,520	760,320	645,120	529,920	414,720	299,520	645,120	529,920	414,720	299,520	184,320
Calipers at Brembo (units)	64,000	48,000	32,000	16,000	64,000	48,000	32,000	16,000	64,000	48,000	32,000
Components at Brembo (units)	1,216,000	1,056,000	896,000	736,000	576,000	416,000	896,000	736,000	576,000	416,000	256,000
Inbound quantities											
Sourcing of Iron to Teksid						460,800					460,800
Sourcing of calipers to Brembo				64,000				64,000			
Sourcing of components to Brembo						640,000					640,000
Consumption quantities											
Iron Consumption at Teksid		115,200	115,200	115,200	115,200	115,200	115,200	115,200	115,200	115,200	115,200
Calipers consumption at Brembo		16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000
Components consumption at Brembo		160,000	160,000	160,000	160,000	160,000	160,000	160,000	160,000	160,000	160,000
Transport											
Semitrailer from port	1					1					1
Domestic trucks	1	10	10	11	10	10	10	11	10	10	10
Shipping transports (cntr 20")	1					1					1
Bulk carriers (Handysized 32 tn DWT)	1					0					1
Rail wagons (22,5 tn)	39					20					20

Source: Screenshot from calculation. For more precise information, please check attached excel file on the appendix num. 2

As we can see, the results in terms of transport are obtained from both the demand for transporting raw material and semi-manufactured components from Asia and from the demand for transporting finished goods to customer.

The main objective of this thesis was to quantify the potential impact of the adoption of AM and this goal has been achieved with the results from the simulation. Therefore, if the production would be done at FCA Tychy, the potential impact of using 3D printing for manufacturing these specific products are presented right below:

Figure 27: Impact on logistics and maritime shipping

Bulk carrier- Handysize	
Capacity	32000 DWT
Frequency	Annual
% usage	17%

Shipping containers	
Frequency	Every 5 weeks
Type	20ft
Annual amount	11

Rail wagon	
Unit capacity	22.5 tn
Frequency	Every 5 weeks
Annual amount	231

Warehouse - contract logistics	
Warehouse space	5000m2
Annual operations	267

Container Truck	
Frequency	Every 5 weeks
Route km	530
Annual amount	11

Semi-trailer to Brembo	
Frequency	Every 4 weeks
Route km	94
Annual amount	13

Milk run truck	
Frequency	daily
Route km	80-120
Annual amount	480

Source: Created based on the calculation's excel file

Based on these figures, the impact on supply chains is quite relevant. From one side, AM could remove the need for global shipping, the quantified annual results for this field are **11 containers for transporting components** and **17% of the space for carrying**

bulk cargo in a bulk carrier. Transport is multimodal and it is required road transport for carrying the cargo from port to door, AM could also eliminate this need. In this simulation, we assume rail freight for connecting port to suppliers, the annual quantified result are **231 full wagons for carrying the iron ore** and **11 container trucks for transporting shipping containers**.

From the other side, it should be emphasized the road transport used for final deliveries which could be impacted. In this field, it is used **13 semi-trailers for transporting manufactured brake calipers to Brembo** and **480 pick-up trucks used for the milk-run to collect cargo from suppliers**.

Furthermore, the other effects on supply chains are related to logistics. Logistics are all these essential services required for coordinating the transport. The impact is extensive and covers many areas like forwarding, warehousing, picking and handling, tug-services, stevedore services, crane services for loading and unloading, port and rail terminals etc.

To sum up, the use of AM performed in this simulation for manufacturing these automotive parts could originate a profound change on supply chains and opening a new paradigm for future manufacturing and logistics. This simulation is illustrating how additive manufacturing is shaping global supply chains.

6. Conclusions

Firstly, we should emphasize that the adoption of additive manufacturing within the production framework is pending for further investments and development.

As we have already seen, the immediate use of SLM for these parts is not suitable yet, but in the coming years could be an advantageous manufacturing since they can reduce complexity and weight. The next automotive era is closer than ever, and it is characterized by EVs, these electric cars are constantly using lighter materials for reducing weight and gaining autonomy. We are convinced that additive manufacturing will revolutionize these new requirements.

According to the future supply chains, the adoption of additive manufacturing doesn't mean a completely removal of global logistics but a large part, making it more sustainable and logical. These new technologies also depend on raw material sourced from Asia, but it reduces the number of intermediaries along the supply chain.

In the future, supply chains could vary depending on who decide to transform their production's lay out from conventional to more technological and this is a service which is turning up since AM is more present worldwide. In this thesis is assumed that the same OEM, Fiat, has invested and own the technologies since they decided to collaborate with an institute of additive manufacturing to develop these auto parts. During these years the number of 3D incubators or specialized institutes in Industry 4.0 has increased drastically, they could play an important role in the future for the irruption at all levels of AM. However, even if these future supply chains involve these new outsourced AM developers, the conventional paradigm will have been innovated in somehow, locating the main production assets on-site instead of off-site, shifting the production from globalization to regionalization.

The irruption of this new industry revolution is concerning the logistics and maritime industry who are raising questions about the future effects on demand. The answer is clear and evident, logistics will become more logical, shorter supply chain but more intensive since shorter lead times and shorter transit times could boost the use of JIT. Moreover, it could speed up the re-industrialization of Europe, making the hinterland wider and prosperous. Logistics will become more sustainable, speeding up the use of transport by rail in order to fulfil the demand for regional transport.

Given the above statements, we strongly recommend the investment on these technologies for different reasons. First, the current globalized network has offshored many industries to Asia in the past years and nowadays we are suffering the consequences of those relocations, being completely dependent on overseas production and any shortage in the sourcing is impacting directly to their supply chains, being out of any alternative local source and unable to meet the forecasted demand. Now we are through a new era where the industry 4.0 could change the rules, approaching the productions to the consumption markets and it is time to give back the production assets to Europe and reindustrialize the region, especially in Spain. These investments could generate value-added services, skilled people, new training and studying trends, foreign business attraction, local interest, industrial development, areas revalue…

Second, governments and the European Union should continue investing and funding on 3D printing hubs and AM projects in order to promote further collaborations and co-workings between companies and AM hubs or AM institutes. Furthermore, by setting up these kinds of facilities, governments are promoting the coming up of new ideas and new projects and consequently further developments on this field.

Third, Additive Manufacturing is offering many applications. Companies should not focus only on rapid manufacturing. Rapid tooling and rapid prototyping are also relevant applications for optimizing production, product development and design manufacturing. Companies should focus on how complementing conventional manufacturing with additive manufacturing.

Fourth, climate change and global warmth are paramount challenges to deal with. The European Union is committed to reduce the environment’s impact on the coming years and every industry is aimed to reduce their wastes and emissions. For these reasons, AM is responding to all these future and present goals since it originates very low levels of waste and pretends to make supply chains more sustainable.

7. References

Attaran, M. (2017, June). Additive Manufacturing: The most promising technology to alter the supply chain and logistics. Journal of Service Science and Management 10(03). Retrieved December 23, 2020.

Barz, A., Buer, T., & Haasis, H. (2016). Quantifying the effects of additive manufacturing on supply networks by means of a facility location-allocation model. Logistics Research 9(1)https://www.researchgate.net/publication/305276754_Quantifying_the_effects_of_additive_manufacturing_on_supply_networks_by_means_of_a_facility_location-allocation_model/citations

Berman, B. (2012). 3-D printing: The new industrial revolution. Business Horizons 55(2). Retrieved December 23, 2020.

Beiderbeck, D. (2018, March 22). The Impact of Additive Manufacturing Technologies on Industrial Spare Parts Strategies. Centre for Technology Management Working Paper Series. doi:10.17863/CAM.21296 https://www.repository.cam.ac.uk/handle/1810/274197

Bhasin, V., & Bodla, M. (2014). Impact of 3D Printing on Global Supply Chains by 2020. Researchgate. https://www.researchgate.net/publication/279810731_Impact_of_3D_printing_on_global_supply_chains_by_2020

BMW. (2020, February 27). With additive manufacturing, BMW perfects 3D printing. https://www.bmw.com/en/innovation/3d-print.html

BMW Group. (2017). MINI Yours Customised: From the original to the personalised unique special. https://www.press.bmwgroup.com/global/article/detail/T0276990EN/mini-yours-customised:-from-the-original-to-the-personalised-unique-special?language=en

Bogue, R. (2013). 3D printing: The dawn of a new era in manufacturing? Assembly Automation 33(4). Retrieved December 23, 2020.

Bonneau, V., Yi, H., Probst, L., Pedersen, B., & Lonkeu, O. (2017). The disruptive nature of 3D Printing. European Commission. Retrieved December 23, 2020.

Böckin, D., & Tillman, A. M. (2019, July 20). Environmental assessment of additive manufacturing in the automotive industry. Journal of Cleaner Production, ELSEVIER. https://www.sciencedirect.com/science/article/pii/S0959652619311631

Carolo, L. (2020, April 23). The 7 Main Types of Additive Manufacturing. All3DP Pro. https://all3dp.com/2/main-types-additive-manufacturing/

Chen, Z. (2016). Research on the Impact of 3D Printing on the International Supply Chain. Advances in Materials Science and Engineering 2016(6):1-16 Retrieved December 23, 2020.

Choong, Y.Y.C., Tan, H.W., Patel, D.C. et al. The global rise of 3D printing during the COVID-19 pandemic. Nat Rev Mater 5, 637–639 (2020). https://doi.org/10.1038/s41578-020-00234-3

Cohen, D., Sargeant, M., & Somers, K. (2014, January). 3-D Printing takes shape. McKinsey Quarterly article. Retrieved December 23, 2020.

De La Torre, C. (2014). Results from the report related to the EC workshop on Additive Manufacturing. European Commission. Retrieved December 23, 2020.

Delic, M., Eyers, D., & Mikulic, J. (2019). Additive manufacturing: Empirical evidence for supply chain integration and performance from the automotive industry. Emerald Insight, 1. https://doi.org/10.1108/SCM-12-2017-0406

Flores Ituarte, I., Chekurov, S., Tuomi, J., & Partanen, J. (2018, October). Digital manufacturing applicability of a laser sintered component for automotive industry: A case study. Research Gate. Rapid Prototyping Journal 24(6) https://www.researchgate.net/publication/328148313_Digital_manufacturing_applicability_of_a_laser_sintered_component_for_automotive_industry_a_case_study

Fraunhofer Institute IAPT. (2020, November 16). And suddenly the printed wheel carrier brakes.. Fraunhofer IAPT. https://www.iapt.fraunhofer.de/en/press-media/Press_releases/Press_Release_Fiat_Chrysler.html

Gaget, L. (2017). What’s the difference between 3D printing and Additive Manufacturing? Sculpteo. https://www.sculpteo.com/blog/2017/10/31/whats-the-difference-between-3d-printing-and-additive-manufacturing/

H. Khajavi, S., Holmström, J., & Partanen, J. (2018, October). Additive manufacturing in the spare parts supply chain: hub configuration and technology maturity. Rapid Prototyping Journal, Volume 24, issue 7. Retrieved December 23, 2020

Janssen, R., Blankers, I., Moolenburgh, E., & Posthumus, B. (2014, April). The Impact of 3-D Printing on Supply Chain Management. Technology Innovation Management Review 5(11):20-25. Retrieved December 22, 2020, from http://3din.nl/wp-content/uploads/2014/02/TNO-Whitepaper-3-D-Printing-and-Supply-Chain-Management-April-2014-web.pdf

Langnau, L. (2020, January 8). 2019 Additive Manufacturing market growth surpassed $10B worldwide. Make Parts Fast. https://www.makepartsfast.com/2019-additive-manufacturing-market-growth-surpassed-10b-worldwide/

Leal, R., Barreiros, F. M., Alves, L., Romeiro, F., Vasco, J. C., Santos, M., & Marto, C. (2017, March 16). Additive manufacturing tooling for the automotive industry. The International Journal of Advanced Manufacturing Technology. https://link.springer.com/article/10.1007/s00170-017-0239-8?error=cookies_not_supported&code=b6bb460b-5c71-4e39-b2fa-d65f0d79b535

Lipson, H., & Kurman, M. (2013, February). Fabricated: The New World of 3D Printing. Journal of Service Science and Management, Vol.10 No.3. Retrieved December 23, 2020.

Lopez Parada, J. (2018). Fabricación aditiva y transformación logística publicado en la Revista de los Estudios de Economía y Empresa nº 9. Retrieved December 25, 2020.

Mewawalla, C. (2019, August). Thematic research: 3D Printing. GlobalData. Retrieved December 23, 2020.

Mohr, S., & Khan, O. (2015). 3D Printing and its disruptive impacts on supply chains of the future. Technology Innovation Management Review 5(11):20-25 Retrieved December 23, 2020.

Pearson, A. (2020). 3D Printed Mass Customization for Daihatsu's Copen Cars. Stratasys. https://www.stratasys.com/explore/blog/2016/daihatsu-3d-printing-effect-skins

Rehnberg, M., & Ponte, S. (2017, June). From smiling to smirking? 3D printing, upgrading and the restructuring of global value chains. Global Networks 18(1) Retrieved December 23, 2020.

Ribeiro, H. (2020, June 26). BMW Group opens its new Additive Manufacturing campus. Metal Additive Manufacturing. https://www.metal-am.com/bmw-group-opens-its-new-additive-manufacturing-campus/

Prototype for small-series production, 2020, Porsche AG. (2020, December 17). Porsche Newsroom. https://newsroom.porsche.com/en/2020/innovation/porsche-protoype-small-production-electric-drive-housing-3d-printer-23235.html

Saunders, S. (2018, November 9). Ford and trinckle Partnering to Automate Design of 3D Printed Production Tools. 3DPrint.Com | The Voice of 3D Printing / Additive Manufacturing. https://3dprint.com/229544/ford-trinckle-automate-design-of-3d-printed-production-tools/

SEAT transforms its Prototype Development Centre and commits to 3D printing. (2020, August 20). SEAT MEDIACENTRE. https://www.seat-mediacenter.com/newspage/allnews/company/2020/SEAT-transforms-its-Prototype-Development-Centre-and-commits-to-3D-printing.html

Sher, D. (2020a, January 6). How major automakers use AM for production today, part 1: Volkswagen additive manufacturing. 3D Printing Media Network - The Pulse of the AM Industry. https://www.3dprintingmedia.network/volkswagen-additive-manufacturing/

Sher, D. (2020b, January 6). How major automakers use AM for production today, part 2: General Motors additive manufacturing. 3D Printing Media Network - The Pulse of the AM Industry. https://www.3dprintingmedia.network/general-motors-additive-manufacturing/

Sher, D. (2020, January 17). How major automakers use AM for production today, part 5: BMW additive manufacturing. 3D Printing Media Network - The Pulse of the AM Industry. Retrieved December 25, 2020, from https://www.3dprintingmedia.network/bmw-additive-manufacturing/

Sher, D. (2020b, January 21). This is how much additive manufacturing is worth in the top 20 global AM markets. 3D Printing Media Network - The Pulse of the AM Industry. https://www.3dprintingmedia.network/the-top-20-global-am-markets/

Sher, D. (2020d, January 20). How major automakers use AM for production today, part 6: PSA additive manufacturing. 3D Printing Media Network - The Pulse of the AM Industry. https://www.3dprintingmedia.network/psa-additive-manufacturing/

Steinberg, G., & Karevska, S. (2019, November 15). How 3DP is moving from hype to game changer. EY Global Consulting Additive Manufacturing/ 3D Printing Leader. https://www.ey.com/en_gl/consulting/how-3dp-is-moving-from-hype-to-game-changer

Tampi, T. (2020, December 1). Fiat and Fraunhofer 3D Print First-of-its-Kind Car Suspension System. 3DPrint.Com | The Voice of 3D Printing / Additive Manufacturing. https://3dprint.com/276291/fiat-and-fraunhofer-3d-print-first-of-its-kind-car-suspension-system/

Wiese, M., Thiede, S., & Herrmann, C. (2020, December 1). Rapid manufacturing of automotive polymer series parts: A systematic review of processes, materials and challenges. ScienceDirect. https://www.sciencedirect.com/science/article/abs/pii/S2214860420309544

8. Abbreviations

AM – Additive Manufacturing

OEMs – Original Equipment Manufacturer

3DP – 3D Printing

JIT – Just in Time

SKU – Stock Keeping Unit

GVC – Global Value Chain

SLS – Selective Laser Sintering

FDM – Fused Deposition Modeling

CAD – Computer Aided Design

STL – Standard Tesselation Language

CNC machining – Computer Numerical Control

RP – Rapid Prototyping

ASA thermoplastic – Acrylonitrile Styrene Acrylate

OEC – The Observatory of Economic Complexity

FCA – Fiat Chrysler Automotives

FCA – Free Carrier (INCOTERM)

ANFIA - Associazione Nazionale Filiera Industria Automobilistica

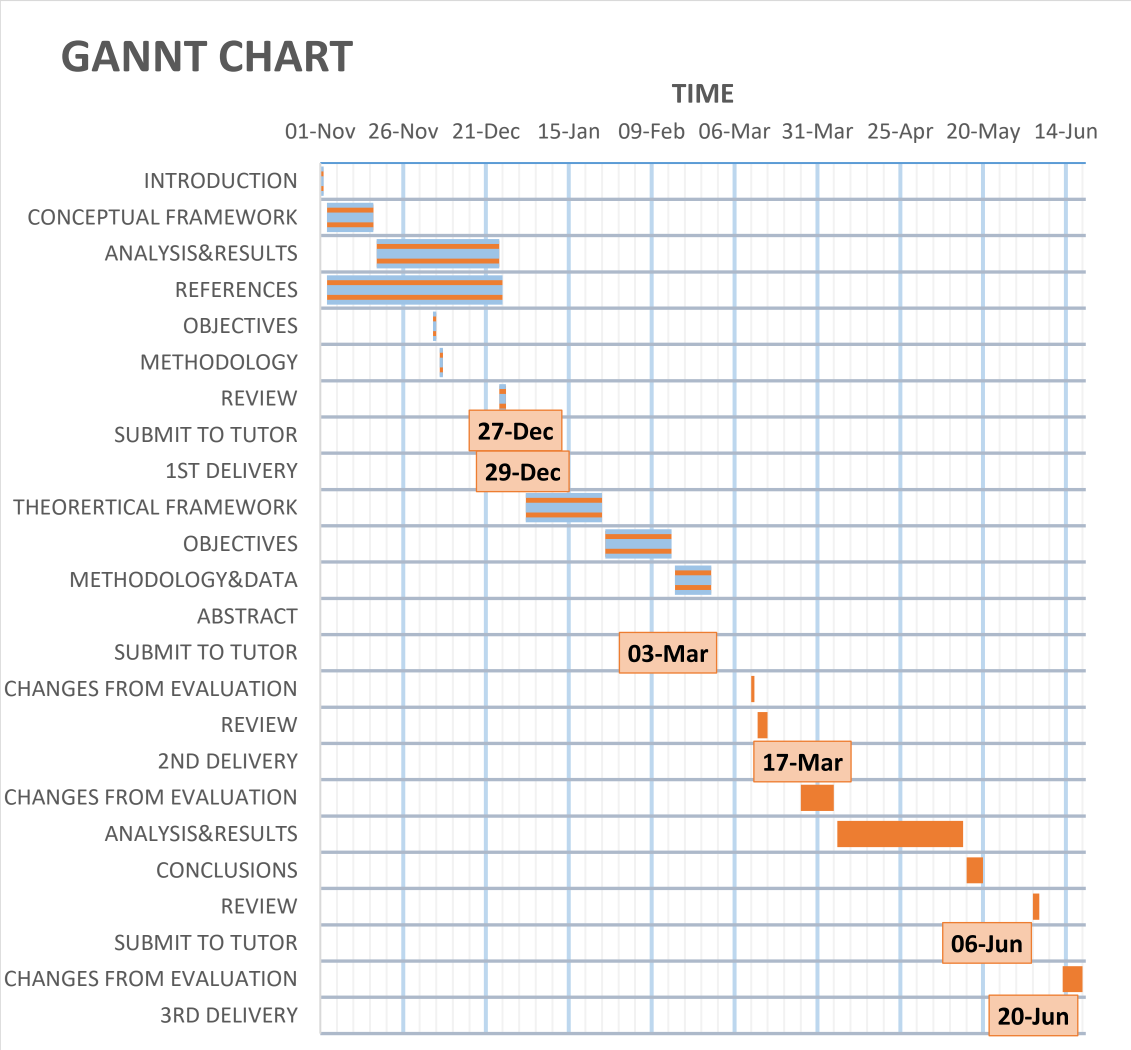
ACEA – European Automobiles Manufacturer’s Association

GDP – Gross Domestic Product

9. Table of figures

APPENDIX

Appendix 1. Timetable for research paper



Appendix 2. Excel file "calculation" attached.