M. Tech Production Engineering

EFFECT OF 3-D PRINTING ON SUPPLY CHAIN MANAGEMENT

A DISSERTATION

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FOR THE AWARD OF THE DEGREE

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Submitted by

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Place: Delhi **SHALLUBHASIN**

Date:

ABSTRACT

3-D printing is a fabrication process by which a 3-dimensional solid object is manufactured by depositing layers by layers on the object. It is emerging as one of the innovative technology highly effect the traditional supply chain management. It has not only enhanced the manufacturing process but also improves the traditional supply chain management. The traditional supply chain is based on a push system whereas an additional supply chain is based on a pull system. In this work we have to find the impact of 3-D printing on supply chain management, what are the risks and opportunities of 3-D printing on the supply chain and, also what are the companies doing to leverages these opportunities and risks. We concluded that the additive supply chain has drastically changed the traditional supply chain in 4 key ways i.e. time, quality, speed, and environment impact.

Also recently in such a condition of the pandemic of COVID19 several institutes have used 3-D Printers to manufacture face shields as well as ventilator splitters, which allow a single ventilator to be used by 2-4 patients simultaneously.

The implementation of the idea in practice will be beneficial to all the sectors. It will result in the effective management of resources which is of immense importance, keeping in mind the sustainable development goals of a blue-chip organization. It will be cost-effective and will reduce the lead time of the supply chain. It will result in increased customer satisfaction as the product will be produced by mass customization and

improved quality. Moreover, this will lead to flexibility in the manufacturing process which will enhance industrial efficiency. So we can say that this research will give us the vision of different industries in India in the coming years.

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ABBREVATIONS

ABS	Acrylonitrile Butadiene styrene
AM	Additive manufacturing
DED	Direct energy deposition
FDM	Fused deposition modelling
PBF	Powder bed fusion
3DP	Three dimension Printing

CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION

3-D Printing is the method of additive manufacturing. In this method or technique, a large range of structures and sophisticated geometries are manufactured from 3-D model data. The printing is done by adding successive layers of material one above the other. Charles Hull developed the process in 1986 known as stereolithography(SLA) which goes through subsequent developments such as powder bed fusion, fused deposition modelling (FDM), inkjet printing and, contour craftsmanship (CC). Additive manufacturing has been largely used in various industries, including construction, prototyping, and biomedical.3-D printing involving different processes, materials, and devices, which has evolved over the years and is capable of transforming manufacturing and logging.

Initially, 3-D printing was extensively used by architects and designers due to its quick and less expensive prototyping ability to produce creative and useful prototypes. The use of additive technologies has minimized the further cost incurred in the development of an assembly. However, from the last few years, 3-D printing has been fully used in various applications. Product design has become a manufacturing problem due to the large cost of making custom-tailored goods for end-users. On the other side, AM can print small quantities of personalized items in 3-D at fairly fewer costs. This is particularly useful in the biomedical field, whereby particular products are tailored as per patient requirements.

A distinctive feature of 3-D printing is consumer fabrication i.e. the development of a collection of customized products in such a manner that every products is special while retaining a fewer cost as compared to traditional manufacturing.3-D printing is free of extra costs related to mould preparing and tooling for a specific product. Hence the large processing of many similar pieces can be as cost-effective. The transition between various designs is straightforward with negligible added expense, and no special planning is

necessary. However, the high costs and time consumption of the AM method remain major hurdles that inhibit mass production.

1.2 HISTORY

The history of 3-D printing is a science which is just 4 decades old. The radical growth of scientific, engineering and technological research has brought to its mature level. 3-D printing technology's historical advances may be represented by various perspectives such as period, specific features, and application. Several historians divided various periods of history into

- Infancy Period:1981 to 1999
- Spring Period:1999 to 2010
- Mature Period:2011 to present

From starting till consideration duration of its existence, 3-D printers were too expensive, but now the cost has dropped to $500-$1000 which make it affordance product.

YEAR	DESCRIPTION OF EVENT
1984	Stereolithography invented by Chuck Hull
1990	3-D printing is commercialized by Stratasys and called it as fused deposition modelling (FSM)
1999	Researcher 3-D print the scaffolding for a new bladder then grow cells on it.
2002	First kidney of animal was printed
2005	RepRap founded with the goal to creating a free/open source printer that can replicate itself
2010	First time human blood vessel is printed by Organovo
March 2014	First 3-D printed skull transplant was done in Norway
April 2014	2000 sq. ft houses are printed by Chinese company using 3-D printer

Table1: History of 3-D printing

1.3 PHASE EVOLUTION OF 3-D PRINTING

The first functional 3-D printer was developed by Charles W. Hull in 1984. He called that stereolithography unit. In the early days, the process was costly and is not practical for every general industry to buy. Nevertheless, when we comes into the 21st era, the price fell significantly, enabling 3-D printers to make a way through other sectors. Selective laser sintering (SLS) and fused deposition modelling (FDM) are the two popular techniques employed in this type of 3-D printing. SLS uses a high-powered laser to combine tiny quantities of carbon, concrete, ceramic, or glass powder into a mass of the appropriate 3-dimensional structure utilizing thermoplastic materials pumped into the frame by indexing nozzles. Eventually, SLS utilizes laser processing to cure the photopolymer resin layer by layer.3-D printing has experienced a three-phase development cycle from the prototyping and mock-up of revolutionary prototypes for prototype manufacturers to end -users buying a 3-D printer and having "factories at home."

EVOLUTIONARY PHASE OF 3-DP	APPLICATION
PHASE 1 Rapid Prototyping	• Product design & architecture • Small batch production of complex parts
PHASE 2 Machine tool manufacturing	• Technology is created to produce finish products • Large quality Replacement Parts • High volume, short lifespan products
PHASE 3 Decentralize Manufacturing	• Consumer goods fast moving & mass produced. • Customers own 3-D printers, design their own pieces to be ready to become a micro-producer.

Table2: Evolutionary phase of additive manufacturing

1.4 PROCESS OF 3-D PRINTING

1.4.1 Creation of virtual model

Modelling software's such as AutoCAD, solid work's, Catia etc are used to make virtual models of component. Design engineers provides the data to create the designs or may obtain designs from existing designs. ANSYS, COMSOL, ABAQUS are some analysing software's that are used for virtual analysis of the object before production. Reverse engineering is also used for creation of models. With the help of UV light scanning of the objects are done i.e., UV light form source hit the target and received back to get scanned.

1.4.2 Understanding the functional part

Designers create the functional parts which are unique structures. The spacing between the parts should be done precisionly by the designers. Singe parts are created by AM process which are further combined together to get whole assembly.

1.4.3 Convert into STL

Standard triangle language (STL) is used for the sliding process. So for this reason models are converted into STL .STL file mainly describe the main attributes i.e. surface geometry of design file. Design file is transformed into triangulated surface using three dimensional Cartesian co-ordinates.

1.4.4 Slicing and creating support

From STL file, contour data is created. As per layer thickness, slicing process is set horizontally. Uniformity is maintained while slicing the materials. Geometry and capability of machine are important factor that determines the thickness of slicing process.

1.4.5 Export to G-code file

G-CODE is created by slicing software for the 3-D printing process. The G-CODE is symmetrical of the CNC machine coding process. The movement of extruder head and platform direction is provided by the coding. In some machines platform is fixed and the extruder moves in all 3 dimensions but in some machines only platforms moves in z direction. All these movements are control by the g-code.

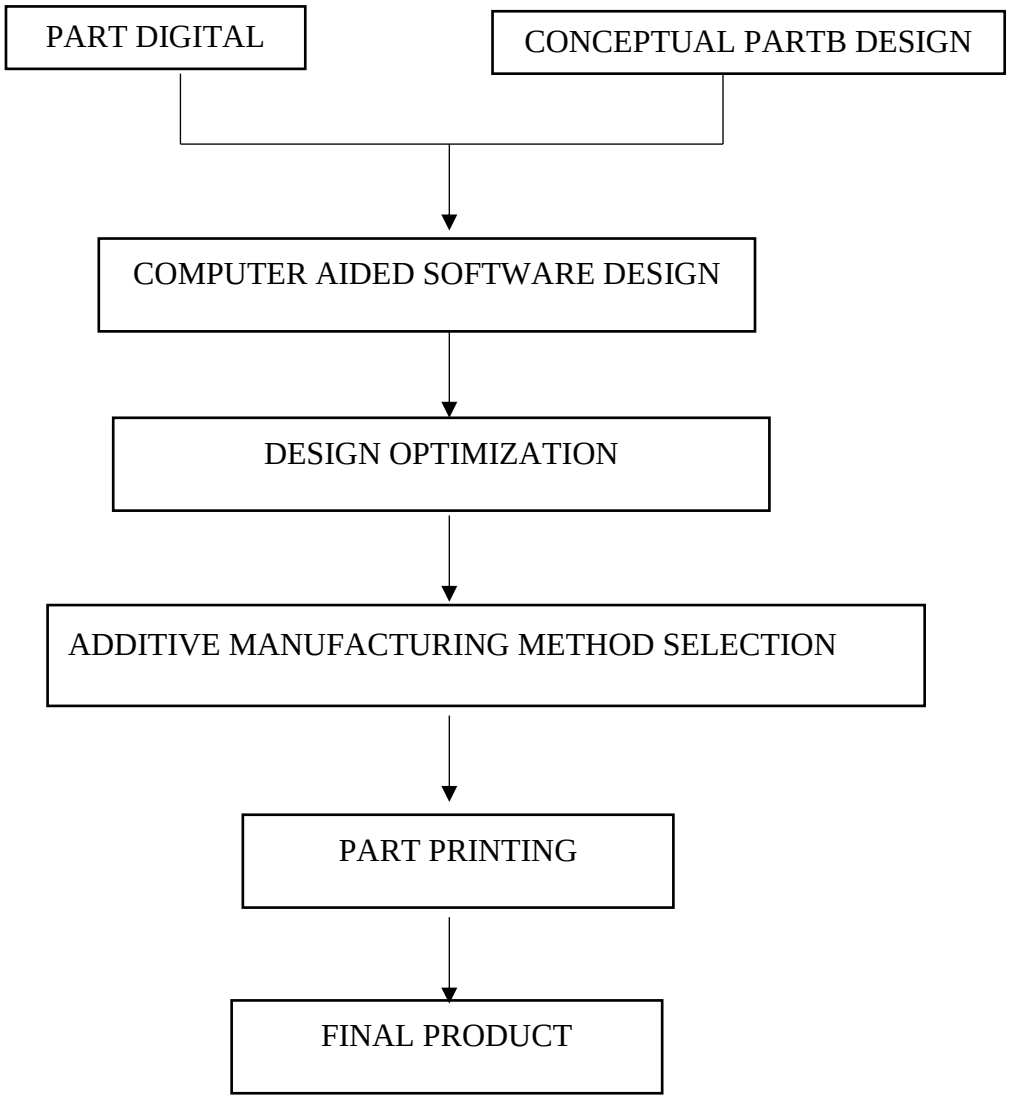

Fig1. Process of 3-D printing

1.5 METHODS OF 3-D PRINTING

Additive manufacturing techniques have been developed to satisfy the need for the fine-resolution printing of complex structures. Quick prototyping, the potential to print massive objects, reduce printing faults, and improve mechanical properties are some of the main factors driving AM technology growth. The key strategies are:

1.5.1 Fused deposition modelling

- Continuous thermoplastic polymer filaments are used in the FDM method to print material layers in 3-D form. The filament is transformed to a semi-liquid state at the nozzle by heating and then extruded onto the top of layers earlier printed. The unique feature of this process is thermoplastic character of the polymer filament which enables filaments to fuse during printing and then to solidify .
- The layer thickness, width, and orientation of filaments and air gap are main processing parameters that affect the mechanical properties of printed parts.
- The key advantages of FDM are a low expense, high speed, and flexibility of the operation.
- The key disadvantages of FDM are: low mechanical properties, bad surface cons istency, and minimal thermoplastic content.

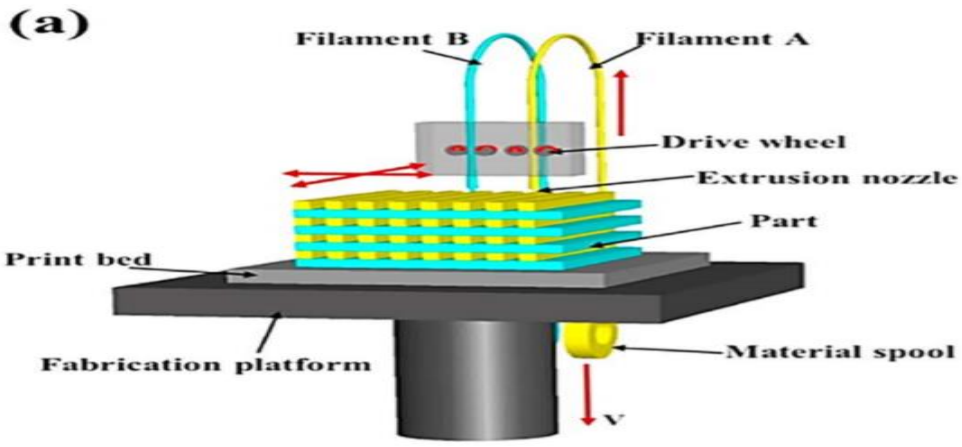

Fig2. Fused Deposition Modelling

1.5.2 Powder bed fusion

- Powder bed fusion processes consist of thin layers of very fine powder which are dispersed over a surface and are tightly prepared. Throughout each plate, the powders are bonded together with a laser beam or binder. Subsequent powder layers are rolled on top of the previous layer and fused until the final 3-D part is constructed. The excess powder is then extracted by a vacuum and further processed if required
- Delivery and processing of the powder type, which defines the consistency of the printed component, are the most critical considerations for the effectiveness of this process.
- The laser should be used only with low-melting / sintering powders while the liquid binder would be used instead.
- Variety of polymers, metals, and alloy powders are used in selective laser sintering (SLA) whereas only certain metals like steel and aluminium can be used in selective sintering melting.
- The major factor that makes powder bed fusion suitable for printing complex parts -fine resolution and high quality
- Scaffolds for tissue engineering, lattices, aerospace, and electronics are some of the industries where this technique has been used.
- High cost and high porosity are major a limitations that one faced during this process.

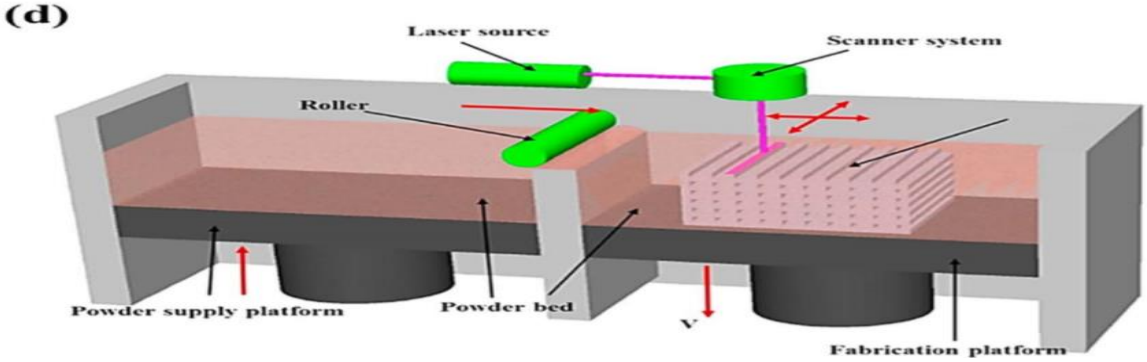

Fig3. Powder bed fusion

1.5.3 Inkjet printing and contour crafting

- The main material that can be used in Inkjet printing is ceramics.
- Complex and advanced ceramic structures are some of the application that can be achieved through this method.
- A stable ceramic suspension e.g. zirconium oxide powder in water is pumped and deposited in the forms of droplets via the injection nozzle onto the substrate. The droplet then form a continuous pattern which solidifies to sufficient strength to hold subsequent layers of printed material.
- Since this method is fast and efficient, therefore flexibility for printing and designing complex structure is possible
- Wax- based inks and liquid suspensions are two main types of ceramics inks used in this process. First, melt the wax -based inks and deposited it on a cold substrate in solidify. On the other hand, liquid evaporation is used to solidify liquid suspension.
- The main factors that determine the quality of inkjet-printed parts are-viscosity of the ink and solid content, nozzle size, particle size distribution of ceramics, extrusion rate, and speed of printing.
- The main limitations of this method are coarse resolution, maintain workability and lack of adhesion between layers
- Contour crafting, works on similar technology as of inkjet is the main method used for large building structures. This method is capable of extruding concrete paste or soil by using larger nozzles and high pressure.

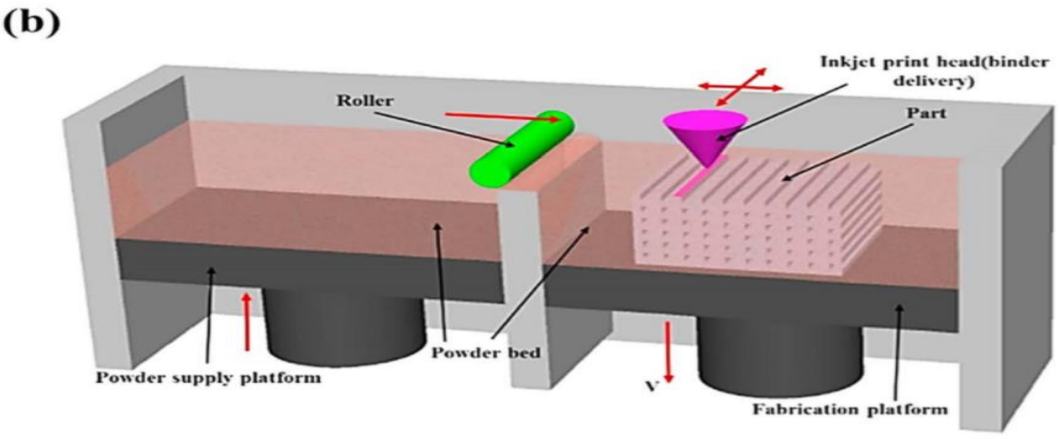

Fig4. Inkjet printing

1.5.4 Stereolithography

- SLA is one of the first additive processing techniques established in 1986. UV light (or electron beam) was used to start a chain reaction on a resin or monomer solution substrate. The monomer is UV-active and instantly transforms into polymer chains after solidifying the resin sheet to accommodate the corresponding materials. The unreacted resin is discarded after printing is complete. LA prints high-quality parts at a fine resolution.
- The main limitation of this process is it is costly, slow, and limited range of materials for printing.
- The main factors controlling the thickness of each layer is the energy of the light source and exposure
- Complex nano compositions are usually formed by this technology only.

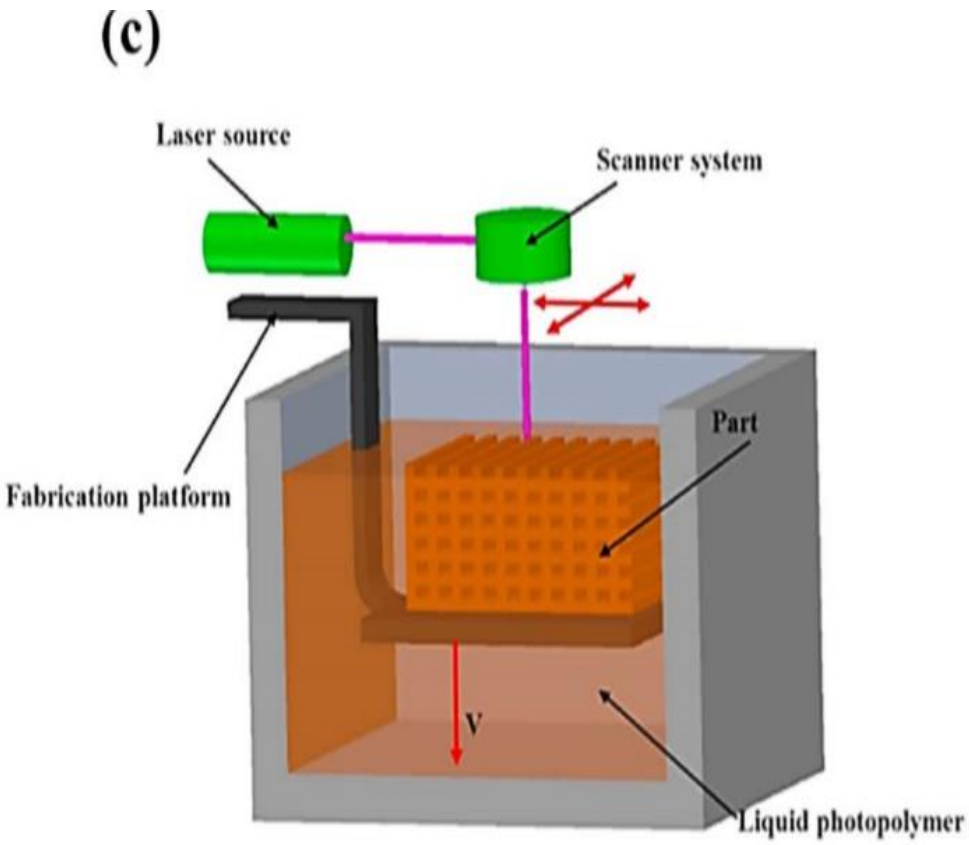

Fig5. Stereolithography

1.5.5 Direct energy deposition

- Manufacturing of high-performance super alloys is possible by direct energy deposition. Laser engineering net shaping (LENS), Laser solid forming(LSF), directed light fabrication(DLF), etc are other names of direct energy deposition.
- Source of energy is used in direct energy deposition method which is directly focused on a small region of the substrate and is also used to melt a feedstock material simultaneously. The melted material is then deposited and fused into the melted substrate and solidified after a movement of the laser beam.
- Larger components with low complexity and also repairing larger components are done by this method.
- The reduction in the manufacturing time and cost, excellent Mechanical properties can be achieved by this method.

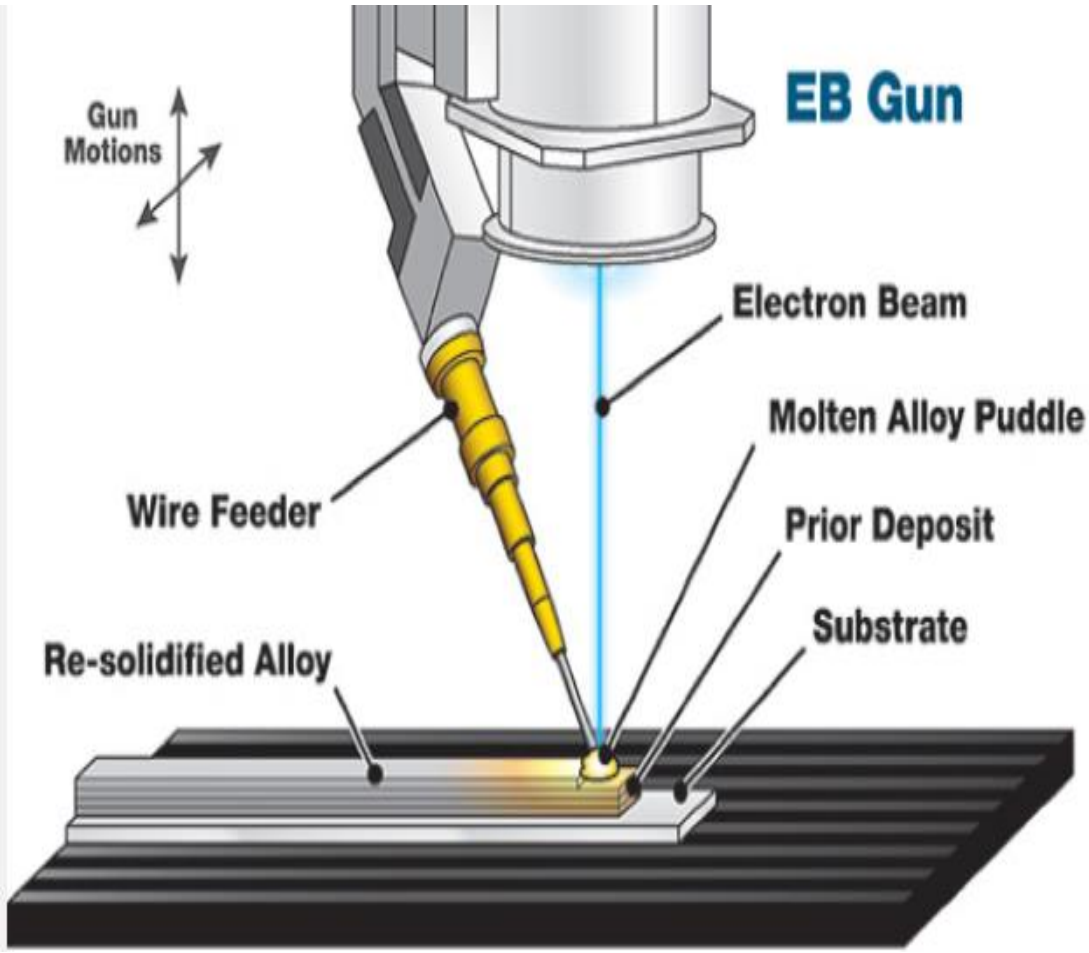

Fig6. Direct energy deposition

METHODS	MATERIAL	BENEFITS	APPLICATION
Stereolithography	A resin with photo active monomers	• High Resolution • Excellent Quality	• Used in prototyping • Biomedical
Powder bed fusion	Compacted fine powder metal, Limited polymers Alloys	• Aerospace • Biomedical • Light weight-structure • Biomedical	• High resolution • Excellent quality
Inkjet printing and contour crafting	In a liquid ceramics ,a concentrated dispersion of particles	• Building • Biomedical • Large structure	• Reduce cost • Reduce time • Excellent mechanical properties
Fused deposition modelling	Continuous strand of thermoplastic polymers	• Advanced composition parts • Rapid prototyping	• Less expensive • Uniformity • Speedy
Direct energy deposition	Metal and alloys in the form of powder or wire ceramics and polymers	• Cladding • Biomedical • Retrofitting • Aerospace	• Less expensive • Limited time • Accurate composition control

Table3: Different processes of additive manufacturing

The table above describe the different methods that are used in 3-D printing technology. The main methods used in additive manufacturing technology are stereolithography, powder bed fusion, direct energy deposition, fused deposition modelling and inkjet printing. The limitations, materials and benefits of all these processes have been discussed in table.

1.6 MATERIALS

The main materials used in additive manufacturing are:

1.6.1 Metals and alloys

Metal additive manufacturing is growing drastically these days. The metal additive manufacturing has been used in various fields i.e. automotive, biomedical, aerospace and biomedical in rapid prototyping and advanced applications. As compared to traditional processing methods, it has more freedom to create complex parts. Powder bed fusion and direct energy deposition are few methods that are used in metal additive manufacturing .In this method energy source such as a laser or an electron beam is used to melt the powder or wire and further solid part is manufactured by transforming melted material layer by layer. Recently new techniques have been developed i.e. binder jetting, cold spraying, friction stir welding, and direct metal writing that can achieved more accuracy or speed. Most of metals that have been used in powder bed fusion are stainless and tool steels, some aluminium alloys, titanium and its alloys and nickel-based alloys. Components with good mechanical properties and complex shapes with high accuracy can be manufactured by powder bed fusion.

- Titanium and its alloys have been used most prominently in industries. Ti and Ti6Al4V have been commercially used in aerospace and biomedical fields.
- Steels such as maraging steels, precipitation hard enable stainless steel, tool steel and austenitic stainless steel are used in AM. These are used for high hardness and high strength conditions along with general purpose applications.
- Austenitic steels and precipitation hard enable stainless steels are sensitive to AM parameters.
- Due to high thermal conductivity in Al, it reduces the internal thermal stresses and allows for faster AM processes. Most commonly used Al alloys are AlSi10 Mg and AlSi12.
- Nickel base alloys have been developed for high temperature applications.
- For biomedical and dental applications, CoCr alloys have been used.

1.6.2 Polymers and composites

Due to large diversity and ease to adopt to different process of 3-D printing, polymers are mostly used in 3-D printing industry. The main form of polymers used in additive manufacturing are reactive monomers, resin or powder and thermoplastic filaments. Polymers and composites have been used in many field from decades such as the aerospace, architectural, toy fabrication and medical fields. Function to manufacture customized complex geometry with high accuracy is the main advantage of composites that enable it to be used in 3-D printing. Due to lack of strength and functionality in polymers products they are often used for conceptual prototypes. UV light has been used in stereolithography 3D printing to polymerise photopolymer resins. Also the properties that need to be improved in photopolymer is thermomechanical properties. Most common polymers used in 3-D printing are polystyrene, polyamides, and thermoplastic elastomers. The techniques that are used to fabricate polymers and composites are stereolithography, selective laser stereolithography, fusion deposition modelling, and 3-D bioprinting and inkjet printing. Photo polymer-based systems are offered fine precision, thin layers and accuracy. Development of resin have improved temperature resistance and strength. For fabricating 3-D printed scaffolds for tissue engineering, PLA-based composites are used. Nanomaterials are other material used in 3-D printing as it improve mechanical and electrical properties along with lowering sintering temperatures. There nanomaterial can be injected in 3-D printing parts either manually or automatically .Also due to excellent strength, good thermal conductivity and lightweight, nanocomposites have been used. Therefore integration of polymer matrix composite and 3-D printing has a drastically affect the industrial manufacturing .However limited selection of polymers and weak mechanical properties of polymer are some of key challenges that are faced in this technology.

1.6.3 Ceramics

High strength to weight ratio is most important factor that leads to production of parts with 3-D printed ceramics. One of the main application of 3-D printing ceramics is creation of strong and versatile ceramic scaffolds with complex geometry for tissue engineering. The main form of ceramic in 3-D printing are powders or inks. Using laser

Powders are sintered and bonded together with adhesive. To print a suspension of ceramics particles normally ink-jet method is used. Dimensional accuracy and quality are main limitation of using ceramics in 3-D printing. The control over microstructure and composition of parts is the main advantages of using ceramics 3-D printing. The main processes used in 3-D printing ceramics are inkjet, powder bed fusion, paste extrusion and stereolithography. Inkjet is the main method that is used in 3-D printing ceramic technology that does not required post processing.

1.6.4 Concrete

Concretes are most commonly man made materials. These are used in construction and infrastructure projects. Extrusion is the main method that has been used in 3-D printing of concretes parts. There is limited number of concretes that are used in additive manufacturing. For example pumpable concrete is good in extrusion process but it does not have enough shape-stability and dimensional accuracy after printing. Self-compacting concrete does not hold its shape so these are not suitable for 3D printing. The main limitations of 3-D printing of concretes are anisotropic mechanical properties, layer-by-layer appearance, and poor inter-layer adhesion .However degree of freedom of design and opportunity to make lightweight parts are advantage of 3-D printing concrete process.

Therefore by combining different materials 3-D printing can manufacture many parts with multifunctional properties. Some of materials can change within a layers while others can change between layers. However there are some limitations to it:

- Only polymers with good flowability can be combined in high-pressure jetting system.
- Materials with similar melting temperatures can be coupled in extrusion- based method i.e. fused deposition method.
- Combination of metals alloys or ceramics are used in DED process as a result more materials can be extruded at the same time
- Also in powder bed fusion, powder with different melting material can be attained.

So, diverse variety of materials can be used in 3-D printing. These material varies from chocolate to advance multi-functional materials. The main form of materials used are filaments, sheets, powder, paste, and inks.

MATERIAL	MAIN APPLICATIONS	BENEFITS	CHALLENGES
Metals and Alloys	• Military • Biomedical • Automotive • Aerospace	• Multifunctional optimization • Mass customization • Reduced wastage of material • Fewer assembly Components • Possibility to repair parts	• Limited selection of alloys • Dimensional inaccuracy • Surface finish is poor • Required post processing
Polymers & Composites	• Aerospace • Automotive • Sports • Medical • Architecture • Toys • Biomedical	• Fast prototyping • Cost effective • Complex structure • Mass-customization	• Weak mechanical properties • Limited selection of polymers and reinforcement
Ceramics	• Aerospace • Automotive • Chemical Industries • Biomedical	• Porosity of lattices' controlled • Reduced fabrication time • Composition and microstructure are controlled.	• Limited choice of 3-D printing ceramics • Improper dimension • Improper surface finish
Concrete	• Infrastructure • Construction	• Huge customization • Less labour required	• Layer by layer appearance • Anisotropic mechanical property

Table4: A summary of main applications, benefits and challenges of the main materials for additive manufacturing

1.7 GENERAL APPLICATION OF 3-D PRINTING

The main advantages of using 3-D printing is to manufacture parts with less equipment's. With the help of digital input, physical parts are made. The general applications of 3-D printing are:

- **Prototypes**

  Prototypes these days are manufacture mostly by AM processes. But all the processes does not create functional prototypes. Material jetting process is used to make prototypes which are aesthetically beautiful and hence used for marketing purposes. Whereas, fully functional prototypes are manufactured by powder bed fusion which are used for product testing.

- **Casting patterns and cores**

  Binder jetting technique is used cast parts of high complexity. Comparatively, AM techniques produce this parts and cores much easily without any tool. For example, a wax or polystyrene casting are produced by AM methods.

- **Manufacturing tools, jigs and fixtures**

  Since these items are produced in small batches, so AM techniques is ideal for there manufacturing. Powder bed fusion with materials like polymers and metals are used for manufacturing as this leads to reduction in non -recurring cost and decrease in manufacturing lead time.

- **Manufacturing blanks**

  Blanks are metals from which containers are made, and further machined to give required dimensions. Powder bed fusion and direct energy deposition are used to manufactures blanks.

- **Manufacturing user end products**

  Powder bed fusion is a process that allows topological optimization of parts. Also with the integration of the components, whole assembly is manufacture. For

example in aerospace industry, ever components need to be qualified as air worthy, huge qualifying efforts can be saved by integration.

- **Repairs of parts**

  Direct energy deposition (DED) is a process through which material can be added to repair damaged in the parts. This can be compared to traditional methods like CNC welding or cladding processes but has to be complemented by design tools to be more effective. Therefore, only in planned and repeatable scenarios, repairing of parts with AM can be done.

Prototypes	**Casting patterns & Cores**	**Manufacture tools, jigs & fixtures**	**Manufacture blanks**	**Manufacturing end-user loaded parts**	**Repair of part**
Sheet lamination					
Binder Jetting					
Material Jetting					
Vat photopolymerization					
Material Extrusion					
Powder bed fusion					
		Direct energy deposition			

Table5. Additive manufacturing process types with applications

1.8 SUPPLY CHAIN MANAGEMENT

Supply chain management is management of goods and services from starting point i.e. supplier till the end user in most efficient way. This is quite complex process which depends upon many factors. The flow of money, product and information is taken place in any kind of supply chain.

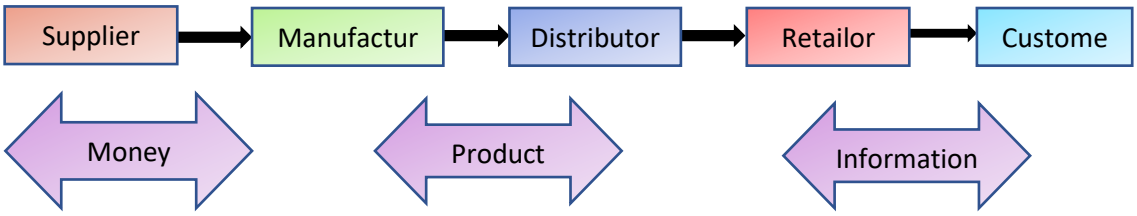

Fig7. Flow of supply chain management

Within the chart, we will see the flow of products, resources, and knowledge from the producer to customers. The statistic indicates the flow of a commodity to the manufacture from the supplier, who forward it to the shipping dealer. The dealer then distributes the products to different shops from where costumers may easily purchase the items. Typical supply chain, therefore, includes a number of phases, i.e.

- Customers
- Retailers
- Distributors
- Manufacturers
- Raw material supplier

1.9 KEY BENEFITS OF SUPPLY CHAIN

The key benefits of supply chain management are as follows:

- Improve of service and customer relationship
- With the minimum delay of product and service create a delivery mechanism
- Increase productivity and maintain business facilities
- Optimize transportation and warehouse cost
- Optimize all cost i.e. direct and indirect cost.

- Operate best by shipping of right products at right time to the right place.
- Enhance inventory management, supporting the successful execution of in-time stock model

1.10 SUPPLY CHAIN GOAL

Every firm aims to match demand with supply promptly with optimise utilization of resources. Some one of main goals of every supply chain are:

- Partners in the supply chain work together at all levels to maximize resource utilization, build standardized processes, and decrease the level of safety stock requirement.
- Reducing spending on the supply chain is very significant, particularly as there is economic instability in businesses over their ability to retain resources.
- Supply chain managers need to focus on creating value for their customers. The best way to satisfy customers ' expectations is to exceed them regularly.
- Increased consumer demands for greater product range, personalized products, off-season inventory quality and fast shipping at comparable cost will be balanced with in-store offering.

1.11 SUPPLY CHAIN PROCESS

Supply chain process is very important in many industries, In case of fast moving consumer goods company, whole reputation of the company depends on its supply chain. These companies invest a lot on their supply chain process to make it work smoothly. The main stages of supply chain are:

- Plan
- Develop
- Return
- Deliver
- Make

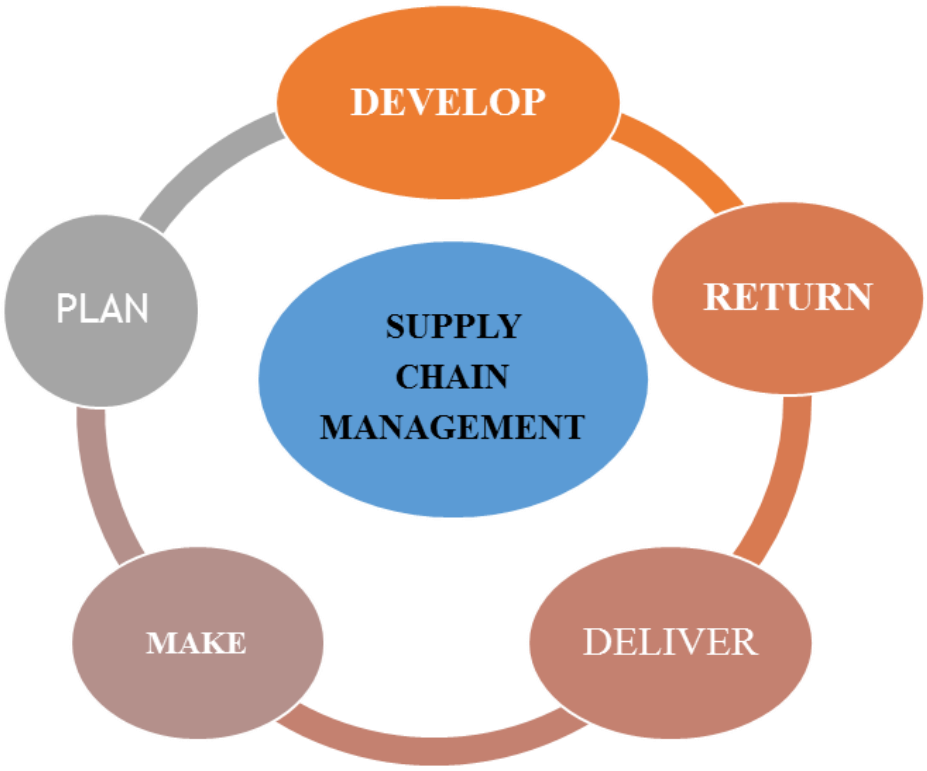

Fig8. Basic components of supply chain management

1.11.1 Plan

Planning stage is the first stage in supply chain process. To know how the goods and services will fill the customer requirements and also to know who all are targeted customer, there is requirement of proper a plan or strategy. In this stage, maximizing the profits is the core point that need to be focus while making a strategy. The organization also need to design the plan for optimum utilization of resources. Planning and develop a set of metrics is the main area that is focused in supply chain management.

1.11.2 Develop

After planning, developing or sourcing is the second stage in supply chain management. Developing a good bond with suppliers of raw materials required for production is the focus area of this stage. This stage looks at various methods of planning related to shipping, delivery, and payment of the product along with identifying dependable suppliers.

1.11.3 Make

The process of making the products as per customer requirement is third stage of supply chain management. In this stage products are assembled as per specifications, quality of products are checked and further packed to synchronize for delivery. Here agenda is to timetable all the activities of the process by the supply chain manager. This stage is most significant stage of the supply chain as it helps the organization to check quality and productive.

1.11.4 Deliver

The delivery stage is the fourth stage in the supply chain process. In this stage, the customer received the product at final location by the supplier. This stage mainly focussed on logistic part, where customer orders are accepted and planning is done to deliver the goods. The delivery stage is often referred to as logistics, where firms collaborate for the receipt of orders from customers, establish a network of warehouses, pick carriers to deliver products to customers, and set up an invoicing system to receive payments.

1.11.5 Return

The final stage of supply chain management is referred to as the return. The defective or damaged goods are sent back to the supplier by the customer. Here customer queries and responses to their complaints are responded by the company as quickly as possible. This stage is the most problematic section of the supply chain as in this stage there is need to develop another network for accepting and storing the damaged products and make sure that customer don’t face any trouble .

1.12 TYPE OF SUPPLY CHAIN MANAGEMENT

There are three types of supply chain management:

1.12.1 Material Flow

Material flow includes a quick and steady movement of an item from the supplier to the customer. It can be raw material, in product inventory, or finish product. This is usually done at different stages of supply chain that includes supplier, distributors, dealers, and retailers. The main challenges which needs to consider in this are that the material move rapidly without any hurdle through all stages in the chain. The quickly it flows, the more it minimizes the cash cycle.

1.12.2 Information Flow

Information/ data flow comprises all the information that basically flows from customers to supplier's end that are quotation request, purchase order, mostly schedules, engineering change request, quality complaints, and reports on suppliers. There is vice versa flow of information as well i.e. from producer's side to the consumer's side. The information that flows from producer side to customer side consist of the presentation of the company, offer, confirmation of purchase order, reports on action taken on deviation, dispatch details, report on inventory,invoices,etc.

1.12.3 Money Flow

Once the invoice is raised by the producer, the order is examined by the client to verify whether he or she has received the correct order or not. On receiving the correct order, the client makes the payment to the respective producer. Debit notes are another form of the flow of money that travels from the producer side to the client.

To efficiently and effectively run the supply chain, the key requirement is to manage all the three flows with minimal efforts.

1.13 DRIVERS OF SUPPPLY CHAIN PERFORMANCE

Responsiveness and efficiency area a key factors of the supply chain management. To have a smooth working of the supply chain there should be a balance between these two key factors. The communication between all drivers is very important to develop the balance between responsiveness and efficiency which ultimately affects the supply chain performance. The main drivers of supply chain performance are: facilities, inventory, transportation, information, sourcing, and pricing. Any organization's aim is to arrange the drivers to obtain the optimal degree of flexibility at the lowest practicable expense, thereby enhancing the surplus supply chain and the financial efficiency of the company. The various drivers of supply chain performance are:

1.13.1 Facilities

Facilities are the real sites where the commodity is processed, packaged, or produced in the supply chain network. The two main buildings are processing sites and distribution areas. The performance of supply chain depends totally on region, flexibility, size, and role of facility.

1.13.2 Inventory

Inventory refers to the safety stock that firms keep in order to fulfil the customer demands. Raw materials, work in process, and finished goods are the part of the inventory in the supply chain management.

1.13.3 Transportation

Transportation involves moving inventory in the supply chain, from the end to another end. Transportation can be conducted in any ways or by the combinations of ways, each with characteristics of its own performance. The responsiveness and efficiency of the supply chain mainly depend on transport choices.

1.13.4 Information

Data consists of details and information across the supply chain about equipment, products, distribution, rates, sales, and consumer. Knowledge is theoretically the increasing output variable in the supply chain because it impacts each other driver directly.

1.13.5 Sourcing

In-Sourcing we particular choose the activities are done in the supply chain and who will perform a particular activity in the supply chain. The main activities are manufacturing, storage and movement of goods, or the management of information. These decisions regarding which functions are performed with the company and which functions are outsources is very important for company development.

1.13.6 Pricing

The amount that the company charges for the goods and services that they provide to the customer are the pricing of that product or services in the supply chain. Demand and supply chain performance is also get affected by the pricing as it ultimately affects the behaviour of the buyer. For examples there may be people who are more concerned about the price rather than quality.

1.14 IMPACT OF 3-D PRINTING ON SCM

In recent years 3-D printing has been increased drastically. It has changes from simple prototyping to fully integrated utilization indirect manufacturing which is the major development of this century. This has drastically changed the supply chain i.e. it has made the supply chain more agile and give growth to new innovations and opportunities but also develop the risk associated with it. Therefore, it is a timely demand to address and study the impacts of 3-D printing on supply chain management. Here term “Impact” specifically refers to the risks and opportunities created as consequences of 3-D printing technology.

CHAPTER2

LITERATURE SURVEY

2.1 LITERATURE REVIEW

To understand what is the basic application of 3-D printing in manufacturing and its effect of the supply chain, it is important to know which exact methods are used in additive manufacturing, the material used, advantages and challenges face during manufacturing. Also, it is important to understand how traditional supply chain works. So to accomplish this the existing research work related to 3-D printing and supply chain should be reviewed.

2.2 LITERATURE REVIEW ON ADDITIVE MANUFACTURING

According to Li Yi et al. (2017), 3-D Printing is the umbrella term for manufacturing processes in which parts are created by adding filaments of material layer by layer. Rapid prototyping, tooling, and direct manufacturing of functional parts and imply revolutionary benefits for the manufacturing industry are main areas of additive manufacturing that he focussed. It discusses 4 issues of AM technologies: it discuss main barriers of AM technology, Total cost that is estimation of AM application, design of hybrid additive-subtractive process chains, and management of quality with AM.

Tuan D.Ngoa et al (2018) reviewed the trending development of the AM technology along with materials and methods that are used in AM technology. The main materials that are used in AM technology along with the benefits and drawbacks includes metal alloys, polymer, composites, ceramics, and concrete, were discussed.

Ngoc A. Nguyen et al (2018) presented the morphological formation within various renewable lignin-based composites containing acrylonitrile butadiene styrene (ABS) and carbon fibres using different mechanical, thermal, and rheological data.

SMFijulkabir et al. (2019) discussed the historical background of 3-d printing. He proposed CFF composites to serve for high load.

Matthias Schneck et al. (2019) aims to analyse and structure the applying functions of additive manufacturing, particular Laser-Based Powder Bed Fusion (LPBF),showing the advantages of and extra values created by technology. Therefore a concept of "Enablers and Objectives" linked to the use of AM is developed.

Kathrin Pfahler et al. (2019) has discussed how companies have started using AM along the product cycle, i.e. from the generation of ideas till the final product is sold to customer. The finding of his research offered the present and future application of AM.

K.Rajaguru et al. (2019) have surveyed on different additive manufacturing techniques, integration of digital pre-processing procedures, and product-based process designing. Also with reduce development and manufacturing time, process of creating new models have been discussed.

L.E.J. Thomas-Seale et al. (2018) identified the difficulties to the progression of additive manufacturing for end-user products considering industrial prospective. The case study has been conducted in various field in UK and 18 barriers have been identified

Tanisha Pereira et al. (2019) compared the advantages, disadvantages, similarities and dissimilarities between AM and SM. He also studied the economic and quality management status of both AM and SM.

Ugur M Dilberoglu et al. (2017) has focused on the role of additive manufacturing in the era of industry 4.0.He reviewed the contribution of additive manufacturing to industry 4.0.

Daniel Delgado Camacho et al. (2017) has discussed the application of additive manufacturing in construction industry. He remarked the potential use of

additive manufacturing in construction industry and also different methods and materials that can be used in construction field with respect to additive manufacturing.

Mohd javaid et al. (2019) take the case study of dentistry and discussed the application and advantages of AM in dentistry and also discussed the steps used to create a 3-d printed dental model. The additive manufacturing technology is used in the case study to manufacture elaborate dental crowns, bridges, orthodontic braces and can also various other models, devices, and instruments with fewer time and cost.

2.3 LITERATURE SURVEY ON SUPPLY CHAIN

AUTHOR	YEAR	CONTRIBUTION
Simone Sehnema	2019	The Study identifies with the development level of round economy appropriation, how well organizations oversee basic achievement factors, and the impact of chosen attributes of firms more elite classes in advancing roundabout economy.
Stefan gold	2017	Conduct the content-analysis based literature review in SCM
Jiang Ying	2012	Examinations of the contrast between the green production network and conventional inventory network and explains the sub-stance of the green store network the board.
Qinghua Zhu	2010	Look at if changed kinds of assembling ventures on ESCC exist. We likewise decide whether the Chinese producer types fluctuating in ESCC vary in their usage of the CE rehearses towards accomplishing the CE-focused on objectives on in-proving both natural and monetary execution.
Carol J. Robinson	2004	Proposed a quality -SCM framework that may be wont to place previous add perspective, yet as establish 3 specific opportunities for future SCQM analysis.

Shilpa Parkhi	2015	Evolution of supply chain management has been studied and understood and future of supply chain management has been explored. Different definitions of supply chain management has been captured and explored.
Inda Sukati	2012	Supply chain performance can be measure by the supply chain management practices. The weaker predictor of supply chain performance is the supply chain management strategy
Mr. Prem Nath Panday	2016	Demonstrated that the simpler way to grow bottom line might through the creation valuable via supply chain management which regularly permits for concurrent price saving and revenue generation.
Carla Roberta Pereira	2014	Understand the role of procurement in characterising and managing inter and intra organizational issues which impact supply chain resilience.
James R. stock	2009	Modification and expansion of supply chain management has been discussed. Components, advantages and activities of supply chain management has been examined.
Dr.S K Banerjee	1998	Examined the effect of globalization on supply chain management
Steffen Butzer	2017	For reverse supply chain, performance measurement system has been developed. It support the remanufacturing industry and circular economy with the minimising reverse supply chain and develop more sustainable process.
M.Agung Wibowo	2015	At construction site, performance of supply chain is measured. Medium or good score is the result of analysis of the performance of supply chain at construction site.
José Crespo de Carvalho	2014	Design the perspective of the evolution of logistics and supply chain management. He purposed that supply chain and logistics is not only area of exchange of goods

		and simple transaction but area of providing services and value creation.
I.J.Chen	2007	Developed an exploration framework that improves understanding of SCM and stimulates and facilitates researchers to understand each theoretical and empirical investigation on the vital constructs of SCM, and therefore the exploration of their impacts on provide chain performance.
M H Sneha Philomena	2018	Discussed the various dimensions of supply chain management and draw SCM from related areas i.e. operational management, logistics management, and value chain management.
Angel Martı´nez Sa´nchez	2005	Find the relationship in automotive supplier between firm performance and different dimensions of supply chain flexibility.
Uta Jüttner, Helen Peck	2003	Discovered different perspectives of supply chain risk management and discussed different strategies of supply chain risk management

Table5: Literature review on supply chain management

2.4 IMPACT OF 3-DPRINTING ON SUPPLY CHAIN

AUTHOR	CONTRIBUTION
M.Varsha shree	The effect of AM in supply chain management incorporates the production process, fixes the time of production, reduced the material wastage, increase flexibility, decrease in the cost.
Henk Zijm, Nils Knofius	Discussed the 3-D printing or additive manufacturing process and its impact on the supply chain by taking a case study of spare parts
Katrin Oettmeier	Demonstrated that the structural composition of entire supply chains can be changed by additive manufacturing as it is a strong technological driver. The systematic analysis about the impact of AM on the network structures in engineer-to-order supply chains is analysis in this case study
Simone Zanoni	Studied supply chain implications of additive manufacturing
Lukáš Kubáč	There are many forma of impact of AM on supply chain i.e. are production processes are simpler, reduction of waste material i.e. is part of leaner manufacturing, highly flexible, cost reduction, quick supply to the demand, and the ability to decentralize production
Mohsen Attaran	New supply chain models are evaluated, potential benefits of AM in challenging traditional manufacturing constraints have been examined, try to explore its impact on the traditional and global supply chain and logistics.
Eren Ozceylan	Compare traditional supply chain with additive supply chain by proposing a simulation model for a healthcare company. Results shows that there are more customer and less lead time in additive supply chain as compared to traditional supply chain.
Samuel H.Huang	Discussed the societal impact of additive manufacturing.The areas that are covered are:customized healthcare products to improve quality of life,environmental sustainability has been improved, increase efficiency and responsiveness of supply chain which ultimately leads to demand fulfilment.

Table6: Literature review on impact of 3-D printing on supply chain management

2.5 FINDING OF LITERATURE REVIEW

Figure below describe the finding of literature review. It shows trends in

- 3-D printing technology or additive manufacturing
- Supply chain management,
- Impact of 3-D printing on supply chain management.

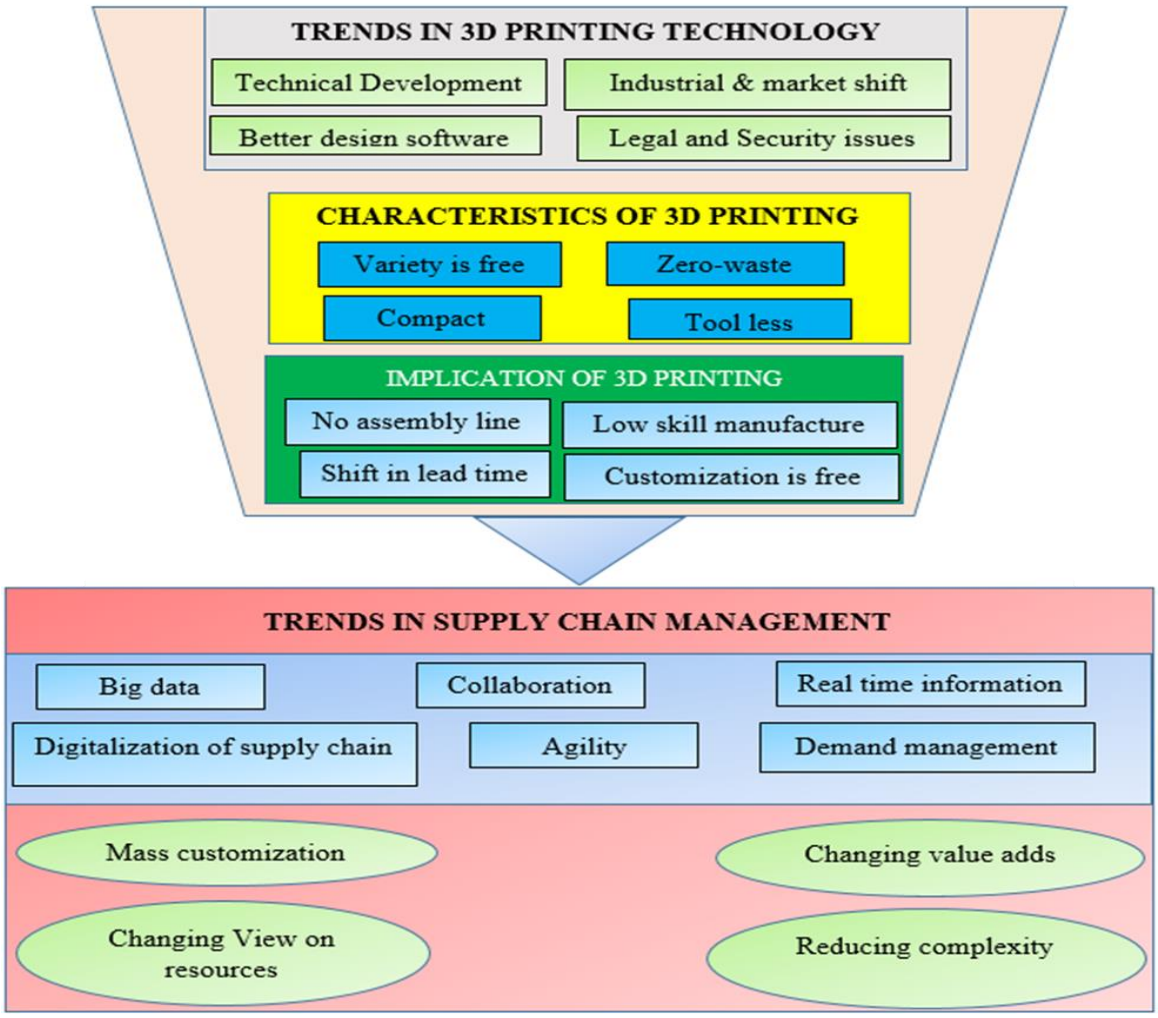

Fig9. Finding of literature review

CHAPTER3

METHODOLOGY

One of the emerging technology which is these days in the market to meet the growing demand is additive manufacturing. In this process, the material is deposited on one another to manufacture the parts as contrary to that of the traditional process. By additive manufacturing, it will lead to the flexibility of design, reduce wastage of material, and also restore damaged parts. There is a variety of applications of additive manufacturing in various areas such as aerospace, construction, food technology, manufacturing, automotive, etc. This chapter discuss about the research path adopted and details of survey conducted to understand the existing application of 3-D printing and to investigate the impact of 3-D printing on supply chain and supply chain management..

The figure below described the areas of subject along with the scope of the study

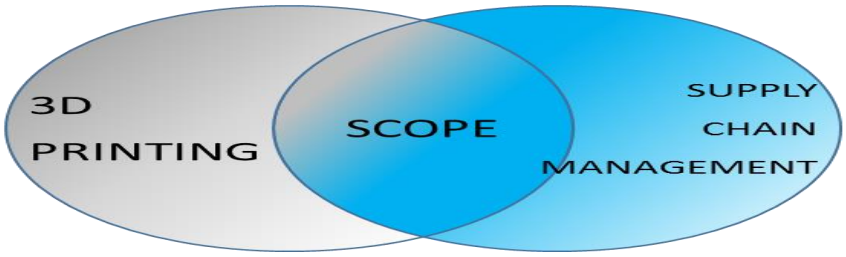

Fig10. Subject areas and scope of study

To follow the structured approach towards filling the scope of this study, the overarching aim is divided into three research questions-

RQ1: What are the benefits and application of 3-D printing.

RQ1: What are the effects of 3-D printing on supply chains and supply chain management?

RQ2: What are the opportunities and risks associated with implementing 3-D printing for the supply chain?

RQ3: What companies do to leverage the opportunities and mitigate the risk?

3.1 RESEARCH PATH ADOPTED

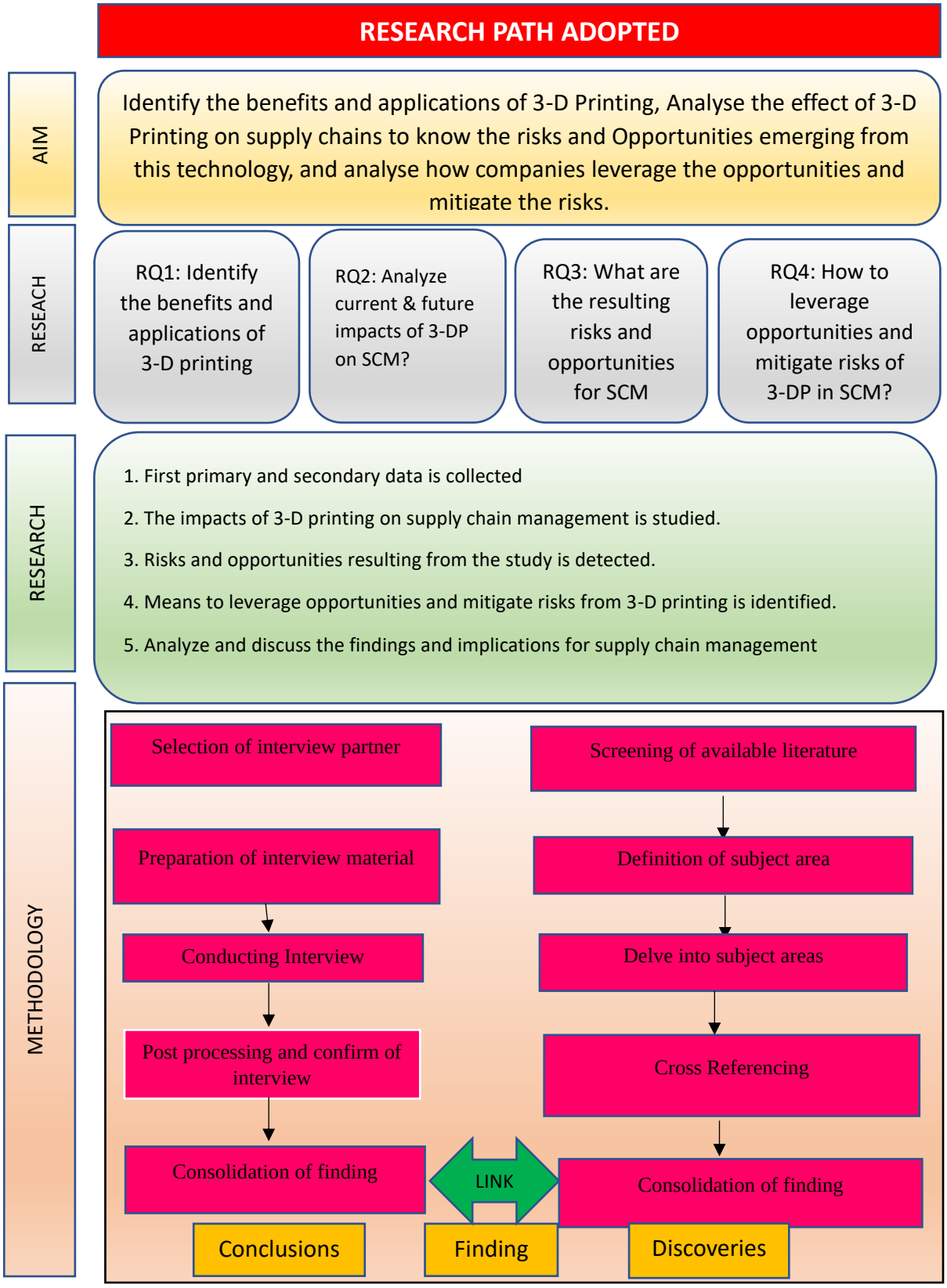

Fig11. Research path adopted

3.2 SURVEY CONDUCTED BY VARIOUS COMPANIES:

The companies such as Nike, general motors, etc were surveyed and interviewed for study the impact of 3-D Printing on supply chain management:

The following questions were taken in goggle doc to gather the information for study the effect of 3-D printing on SCM:

Q1. Name of the person

Q2. Email id of the person

Q3. Company name to which he/she belongs

Q4. Do your company used 3-D Printing technology?

- Yes
- No

Q5. Which method of 3-D Printing is used in your organization?

- Fused deposition method
- Inkjet printing and contour crafting
- Stereolithography
- Powder bed fusion

Q6. Which material is used in additive manufacturing technology in our organization?

- Metals and alloys
- Composition and Polymers
- Concrete
- Ceramics

Q7. Is there a high degree of customization of products in your company through 3-D printing?

- High level of customization
- Medium level of customization
- Low level of customization

Q8. What is the impact of 3-D Printing on lead time?

- High impact
- Medium impact
- Low impact

Q9. Does 3-D printing reduce the complexity of the supply chain network?

- High reduction
- Low reduction

Q10. Does 3-D Printing create the opportunity of rationalizing logistics and reduce inventory

- Yes high impact
- Yes Medium impact
- Low-Rarely impact

Q11. Does 3-D Printing create a risk of major layoff?

- Yes
- No

Q12. Does 3-D Printing decrease the quality of product?

- Yes
- No

Q13. What are the areas where impact of 3-D printing effect in your company?

- Complexity
- Cost
- Time
- Flexibility

Q14. 3-D Printing leads to which type of supply chain?

- Pull supply chain i.e. demand driven
- Push based supply chain i.e. supply driven

Q15. What level of inventory need to be consider in warehouse while manufacturing through additive manufacturing?

- High
- Medium
- Low

Q15. Do we leverage the opportunity of 3-D printing on SCM with technology?

- Yes
- No

The information collected from various sources are studied and further analysis are done to drawn the results and conclusion.

CHAPTER4
RESULTS

4.1 APPLICATION OF 3-D PRINTING

The drastic and quick changes in the customer requirement can be fulfilled in industries like automobiles and aerospace by utilizing AM technology. This technology has shaped the direction and develop technological innovations that help the companies to meet with the demands of the market. AM is the biggest innovation as it opens up the new scope in the companies and also provides many possibilities to improve manufacturing efficiency. The main sector which used 3-D printing are:

- **Aerospace industry**

  In the aerospace industry, titanium and nickel alloys are used to make a lightweight devices. The main factors these days that need to be considered in the aerospace industry are weight and fuel saving. This can be effectively done using additive manufacturing technology.

- **Medical and dental industry**

  In the medical and dental industry, for fabricating orthopaedic or orthodontic implants titanium alloys have been extensively used in the form of powder. Mass customization at an affordable price is the main driving factor for implementing additive manufacturing in this industry.

- **Automotive**

  The Automotive sector largely depends on additive manufacturing technology. This sector is the second largest sector that produces products by additive technology. Design flexibility is the major factor that leads to an increased used of additive manufacturing in this sector. Apart from design flexibility, rapid prototyping is another factor that plays role of using additive manufacturing in this sector.

- **Consumer Products**

  This is the largest sector that used additive manufacturing to produce products. Apart from the largest, this sector is the most diverse sector that produces a large range of products by embracing additive manufacturing technology. The high level of customization is the main factor that leads to use this technology in this sector.

- **Construction**

  Most of the work of additive manufacturing in the construction industry works around the extrusion process of materials using aggregate-based material for a high level of application. The use of polymers as a material has been effective for aesthetic purposes that have unique designs.

- **Food Industry**

  The benefits of 3-D printing are various in food industry. It helps in fabricating complex designs that are required in the machinery of food industry. It helps in calibrating the tools of food industry.

- **Education Industry**

  Additive manufacturing has made learning process much easier at all the level i.e. primary level to university level. It helps students to print design the components much easily as compare to other outside sources.

INDUSTRY	APPLICATION
AEROSPACE 1.Design & rapid prototyping 2.Component Manufacture 3.Mass customization	1. Light weight of aircraft 2.Engine components 3. Flight-certified hardware 4.Airplace landing gear assemblies
MEDICAL 1.Design and rapid prototyping 2.Manufacture at requirement 3.Mass customization	1. Manufacture human organs 2.Reconstructing bones, body parts
AUTOMOTIVE 1. Simplify production process 2. Component Manufacture 3. Design &Rapid prototyping 4. Manufacture at requirement	1.Light weight 2.Cooling system for racing cars 3.BMW is using print hand tools 4.Can be used in a backup capacity
ARCHITECTURE & CONSTRUCTION 1.Design & rapid prototyping 2.Manufacture at requirement	1.Design & rapid prototyping 2.Manufacture at requirement

Table7: Application of 3-D printing

4.2 IMPACT OF 3-D PRINTING ON MANUFACTURING

There is a drastic impact of 3-D printing on manufacturing industries. With the innovation of additive manufacturing, there have been the following improvements in manufacturing. There has been

- **Ability to produce complex structure**

  The ability to design any part is the main benefits of AM technologies. There is a significant improvement in manufacturability due to freedom of design as compared to traditional processes and thus more usage-driven designs are fabricated. In additive technology, a unique balance between strength and material requirement can be achieved to manufacture complex parts that are not feasible with traditional technologies. For example, in the aerospace industry, lightweight designs are produced only with additive manufacturing technology which ultimately needs to fuel saving.

❖ **Reduce material wastage**

In additive manufacturing, reduction in material wastage is another factor that is of significant importance. The materials that are fed to an AM machine is available in different forms that those used in traditional processes.

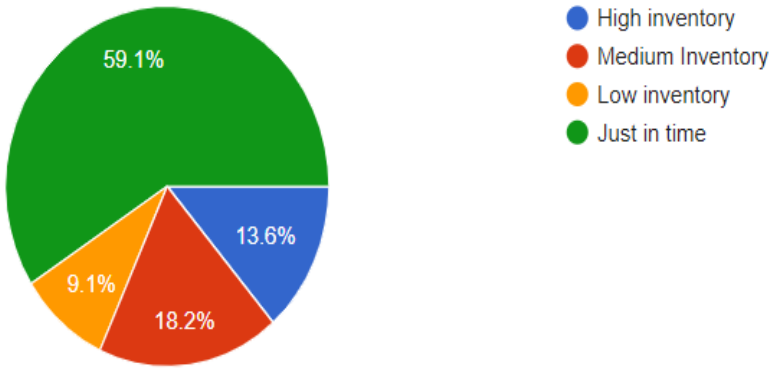

Fig12. Impact on inventory and material in 3-D technology

Above figures describes that there is less material wastage and less inventory in case of 3-D technology. Most of them are manufactured on demand

❖ **High level of customization**

A High level of digitalization is another factor that is leading this technology in the industry. The availability to design the products according to customer requirements and manufacture them when there is a demand with the available material is a major throwback of this technology. There is no need for any tooling or product dependent set-up process which make AM a highly flexible technology.

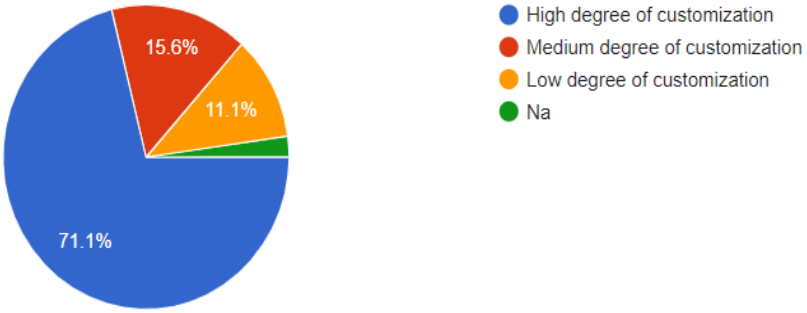

Fig13. Level on customization in 3-d technology

The above figure shows that additive manufacturing leads to high level of customization in the industries. 71.1% people says that there is high level of customization of product and this is important feature of additive manufacturing which bring new era of manufacturing.

- **Faster time to market**

  Since there is close intertwine between the design phase and manufacturing phase in this technology, it leads to a reduction of several steps in assembled processes i.e., only raw material is required to make products. Therefore AM May drastically decrease the time to market which is very important in today's global competitive environment.

- **Shorter manufacturing time**

  3-D printing leads to new era of industrialization. Micro manufacturing is itself done by consumers these days i.e. personal items are printed by consumers only. This leads to reduction in manufacturing lead time.

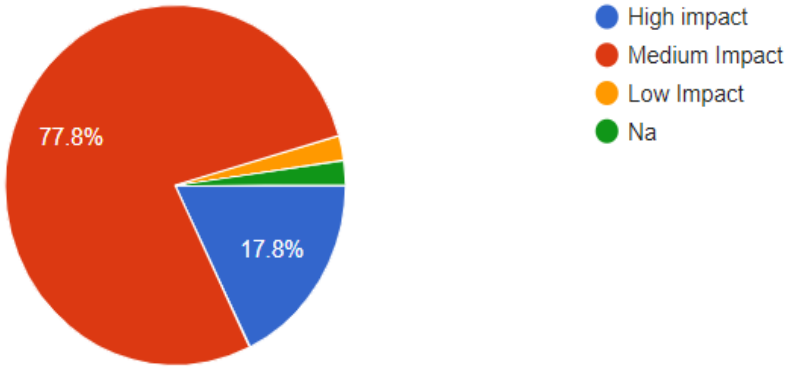

Fig14. Impact on manufacturing lead time in 3-D technology

Above figure describes that 77.8 % people agree that through additive manufacturing, lead time is reduced in making the product which is economical beneficial to industries.

MANUFACTURING IMPROVEMENT	KEY ENABLING CAPABILITIES
Increase in efficiency of industry	1. Less requirement of the material 2. Multi material capability 3. Simple production processes, reduce cost
High level of Customization and just in time manufacturing	1. Customization of the product as per customer specification 2. Increase complexity in lesser cost
Decentralized Manufacturing	1. Manufacturing is done closer to customer 2. At place of use, manufacturing is done.
Batch Manufacturing	1. Small volume of products can be manufactured at lesser cost 2. Reduction in the investment made for establishing huge set ups of design process and tools.
Rapid Prototyping	1.Decrease in time-to-market 2.Decrease product development cost
Machine tool Manufacturing	1.Labour cost is decreased 2.No need to keep inventory ,thus decrease warehouse cost 3.Availability of high level of customization at lesser cost
Environmental impact	1. Sustainability is improved 2.More positive impact on environment
Improvement in quality	1.Reduce overall cost by simplifying the process 2.Manufacturing lead time is reduced 3.Instant change in manufacturing as per demand requirement

Table8: Impact of 3-D printing on manufacturing

4.3 IMPACT OF 3-D PRINTING ON SUPPLY CHAIN MANAGEMENT

With the introduction of additive technology in manufacturing, it affects the traditional supply chain drastically. AM supply chain is stated as interconnected between different stages of the supply chain that delivers goods and services, as per the requirement of the end-user of products manufactured using AM technology. There are various members that constitute in this supply chain i.e. machine vendors, material manufacturers, software providers, logistics operators, and research centers. Additive manufacturing will lead to open new opportunities and also emerges as a valuable way to increase the efficiencies in the supply chain. The main impact of 3-D printing on the supply chain is on the following factors:

- **Supply chain structure:**

  In traditional methods all the components that need to be assembled are required before starting the manufacturing additive manufacturing technology due to integration of functionality of component with 3-D -printed part, the number of components is skipped. As a result, there is no need for supply relations that are present in the traditional supply chain. Moreover, due to reduce synchronization efforts, there is no need for production planning at multi-level and therefore lesser cost and risk is added. From survey conducted, 88.6% agrees that with the additive technology, there is huge impact on supply chain. There is reduction of stages of supply chain which ultimately leads to more responsiveness and less lead time.

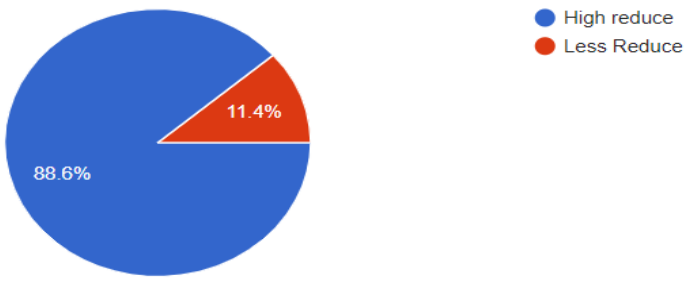

Fig15. Impact on supply chain due to 3-D technology

❖ **Supply chain inventory**

Since final products are manufactured directly from raw material due to the Consolidation of functions, there is no need to keep the inventory of products i.e. downstream stocks are no longer needed. In the case of customized products, there is no requirement of inventory as all the products are manufacture on customer request. These day modular product designs are used on large scale to customize the products as per customer specialization. This customer is satisfied by combining the right components in one final product. Also due to the high digitalization of the manufacturing process, inventory of components may be partially avoided. Since this technology leads to less material wastage, there will be a less inventory.

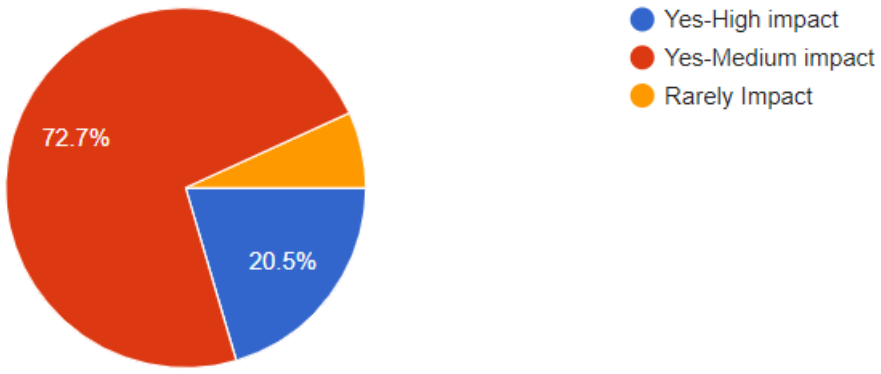

Figure16: Impact on inventory management in 3-D technology

Above figure describe the impact of 3-D printing on inventory management.72.7% people agree that's by apply additive technology, there is high impact on inventory management. Products are manufactured on demands and high level customization make it easier for industries.

❖ **Component lead time**

In traditional assembly processes, most of the components are available through external sources i.e. external suppliers. In some cases company itself manufacture the parts in the same factory. In that case, advance planning of components is required. Such components are typically manufactured in batches for the reasons of efficiency, blowing up lead times and inventories even further, while additional delay may occur due to queueing problems in case of limited machine capacity. Hence, lead time reductions in the overall supply chain can be easily achieved by consolidation AM.

❖ **Customer responsiveness**

In traditional manufacturing, due to high inventories of either final products or modules, there is a quick response to the customer's need. As a result, there will be a huge investment of capital which ultimately leads to a reduction in company liquidity. In another case, if there is less inventory of the stocks there will be more customer waiting time as specific components need to order from supplier end which results in a reduction in the sales of the company. Therefore a balance between responsiveness and availability of good needs to be maintained which can be accomplished by AM.

Therefore in short, there is 4 areas where impact of 3-D printing on supply chain can be noticed

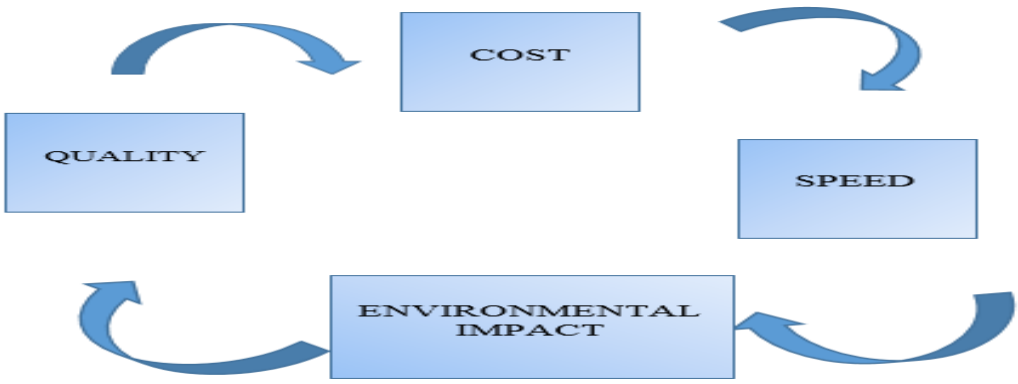

Figure17: Key areas of impact of 3-D printing on SCM

KEY FACTORS	ADVANTAGES
Reduction in overall cost	Reduction in the inventory stock Decrease the requirement of large volume production facilities Cost of transportation is reduced Penalty for redesigning is reduced Economical lot size decrease More economical and effective packaging solutions Vetting out design Labor inputs is reduced Reduction in tooling cost High level of customization
Quick response to the customers	Reduce the time lag between design & product Lead time is reduced Encourage Just in time manufacturing Increase flexibility of process Supply Chain disintermediation Hedge against disruption
Improvement in quality	Production waste is reduced Quality of product is improved Customer feedback is incorporated Industries have more optimum products Excess parts that are heavy are diminished Demand uncertainty is managed
Environment Impact	Sustainability is improved More positive impact on environment

Table9: Impact of 3-D Printing on Supply chain management

So from above table, we conclude that companies that are manufacturing components using additive manufacturing alter the supply chain from the traditional method to AM supply chain. This leads to improving performance in the following four key areas of cost, speed, quality, and environmental impact.

4.4 TRADITIONAL SUPPLY CHAIN VS AM SUPPLY CHAIN

These days, AM has drastically replaced the traditional methods and has become the future vision of many sectors of industries. Product customization is easily done using AM and this leads to significant impacts on production and distribution. By indulging clients in the design and production stages AM has the potential to reduce costs and increase profits. As a result, the supply chain can quickly react to changes in the marketplace.

TRADITIONAL SUPPLY CHAIN	AM SUPPLY CHAIN
It leads to Push supply chain	It leads to Pull supply chain
There is longer manufacturing lead time	There is Shorter manufacturing lead time
Transportation cost is high	Transportation cost is low
Distribution network is very complicated	Simpler distribution network
There is Dependency on economics of scale	There is Dependency on economics of scope
Longer customer waiting time	Quick respond to customer needs
Demand uncertainty is problem	Demand uncertainty is easily managed
Inventory requirement is high	Inventory requirement is less. Just in time manufacturing
Manufacturing is done away from customers	Manufacturing is done near by customer

Table10: Traditional supply chain vs Additive supply chain

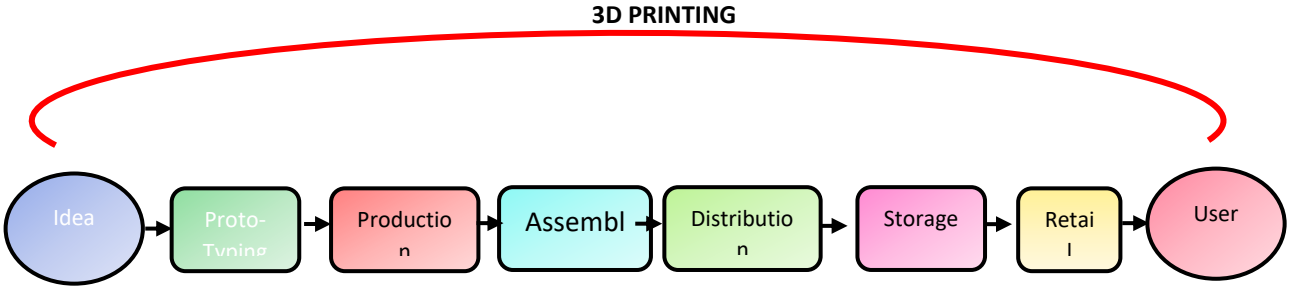

Figure18: Traditional supply chain vs Additive supply chain

4.5 RESULTING RISK AND OPPORTUNITIES FOR SUPPLY CHAIN MANAGEMENT

After analysing how 3-D Printing puts an impact on supply chain management, we figure out apart from impact there are a lot of risks and opportunities that are attached to these impacts. Based on the result of impact on the supply chain, we can decide whether that impact is a risk or an opportunity for the supply chain. For example

- **Rationalization of logistics and reduction of inventory**

  The Rationalization of logistics and reduction of inventory has come with both opportunities as well as risk. In case of opportunities, this leads to a reduction in overall cost i.e. by saving labour cost, transportation cost, and inventory holding cost. In case of risk, this leads to major layoffs as most of the work is done digitally. Also reduction in safety stock during high demand in the peak period leads to fewer profits.

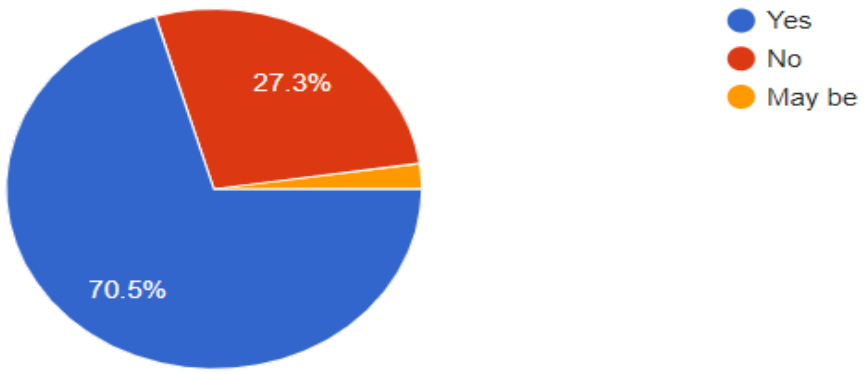

Figure19: Impact on layoff in 3-D technology

The above figure describes that 70 % people agrees that 3-Dprinting leads to major layoff as most of work is done by skill person.

- **Decentralization of manufacturing**

  The decentralization of manufacturing can be seen as both opportunities as well as risk to supply chain. It can make a supply chain more agile in the market place which leads to lower logistic cost. But also it leads to missing the economics of scale which is a major risk associated with it.

- **In house prototyping**

  To reduce the cost and shorten lead time many companies have started in house prototyping. For local companies, this is a great opportunity as it leads to more profits but at the same time, it is a risk on the prototyping service industry as there will be a reduction in the business.

To identify whether the impact is opportunity or risk, there is a need for strong evaluations. The process of evaluation is critical as it affects the supply chain. Also, there is a variety of trade-offs between risks and opportunities that are connected to certain impacts of 3-D printing on supply chains. In these cases, it is crucial to identify both positive and negative aspects of the impact, and include them equally in the assessment. Below example show that many of the impacts of 3-D printing are trade-offs between risks and opportunities:

- At one end 3-D printing has the potential to have a simpler supply chain by consoling components and inventory but on other hand, the process of testing and quality check are far more complicated and complex which increases downstream supply chain complexity.
- By producing products through rapid prototyping, there will be a decrease in supply chain lead time. Also, this process is so quick that it speeds up the entire development process. However, some changes in the process can lead to the creation of other bottlenecks in the process, which can in turn harm lead times.
- 3-D printing technology leads to efficient utilization of resources, which improved supply chain sustainability. However, because 3-D printing enables engineers to do more iteration steps while creating and testing prototypes, using more material in the process bears the risk of negative impact on supply chain sustainability as a potential consequence.

In most cases whether the impact is opportunity or risk is more straightforward. For example, Mass customization which is a major feature of 3-D printing is a big opportunity for the manufacturing sector as it directly targets customer needs an opportunity for flexible and agile supply chain can be achieved easily with 3-D printing which ultimately helps the companies for smooth functioning. The technology also adds new sources of

revenue generation, a focus on the key value-adding activities in a supply chain as well as new possibilities in product design. In contrast to that, the main risks of 3-D printing are the lack of quality and accuracy for advanced applications as well as the uncertainty about the future technical developments and the corresponding financial risks of an investment.

4.6 HOW TO LEVERAGE OPPORTUNITIES AND MITIGATE RISK OF 3-DPRINTING IN SCM:

From all the data collected and the interview conducted, we have find the many important practices of supply chain management and 3-D printing. To take advantages of opportunities and mitigate the risk variety of action or task a company takes. The following is a comprehensive summary of these actions:

- **Responsible leadership**

  To take full use of advantages of 3-D printing on the supply chain, long leadership is required which has a clear vision of the purpose of the supply chain. There should be a responsible supply chain manager which works dedicatedly to run the smooth functioning of the supply chain. Acceptance for the technology must be ensured by educating and informing all the parties about the intended role of 3-D printing in the supply chain, as well as by clear ownership of the technology by supply chain managers.

- **Better technology**

  Quality of the material is another issue that is common while manufacturing components with AM technology. This issue can be eradicated by using the innovated methods for indirect components that are not part of the final product. This solution can help to realize opportunities in a variety of fields, such as the production of tools, supporting structures, and equipment for the testing and cleaning procedures of parts.

Therefore in the preparation for the risks and opportunities of 3-D printing, it is critical to include all the potential impacts of the technology on the supply chain in the evaluation process. Many of the implications that are the result of the integration of 3-D printing into a supply chain setup are not immediately obvious and can have largely disruptive impacts if they are not uncovered in phases early on during the assessment. An end-to-end supply chain perspective is, therefore, necessary to identify all risks and opportunities and develop appropriate actions.

CHAPTER 5

CONCLUSIONS

In detecting the impact of 3-D printing on SCM, the project gives a new vision of the AM supply chain which is the future of many sectors in the coming future. This study aims to focus on the intersection between two distinct areas: supply chain management and 3-D printing or additive manufacturing. We find out how 3-D printing has drastically affected the manufacturing system. It leads to an increase in industrial efficiency, decentralized manufacturing, rapid prototyping, and improved quality of products. Moreover, we find that most of the companies which are manufacturing components with AM technology have altered their supply chains to increase the performance in the following four key areas of cost, speed, quality, and environmental impact. By using additive technology this has changed the traditional supply chain drastically. It leads to a pull supply chain, decreased lead time of manufacturing, reduced transportation cost, reduce inventory, and less complex supply chain. The output of the impact of 3-D printing on the supply chain needs to be evaluated to decide whether it is associated with risk or opportunity. This is a critical process that needs to be evaluated thoroughly.

The results from this study can serve as a valuable basis for further research in the scientific area of the impacts of 3-D printing and corresponding risks and opportunities for the supply chain. Moreover, the gaps between literature and industry that have been uncovered by this research project leave open opportunities to expand the body of knowledge in breadth and depth.

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