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Effect of 3D printing on supply chain management

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ABSTRACT

The recent revolution in the field of manufacturing is 3D printing or Additive Manufacturing (AM). Recently, AM technology is emerging as an eye opener for creating complex geometries with desired material and to improve the designing and modelling of implausible structures. It leads to the disruptive innovations that creates a global impact on the logistics of industries and the supply chain. The main competence of this technology is to fabricate the products closer to the expectations of customers around the world and to customize those products in real time. It has great advantages over supply chain management by the means of reduction in inventory, shipping costs and capital expenditures on factories and warehouses which provides the potential to evaluate the transformation of global supply chain management. The main objective of this review is to achieve knowledge on utilization and contribution of 3D printing on supply chain management and to explore the impacts of AM in supply chain management.

Selection and peer-review under responsibility of the scientific committee of the International conference on Materials and Manufacturing Methods.

1. Introduction

The integrating technology that comprises its enormous application across the globe is popularly known as "additive manufacturing" and the essential factor employing this manufacturing process is described as "3D printing". In this process, the three dimensional components are built on a layer-by-layer basis through series of cross sectional slices [1]. 3D printing is defined as a methodology that uses three dimensional computer aided design (CAD) datasets to produce 3D haptic physical model. Depending upon the production method it can be varied as rapid prototyping, solid free form, computer automated and layered manufacturing [2]. Recently 3D printing has enrolled in health care applications rather than manufacturing industries thereby providing new opportunities for scientific innovations and research [3]. Primarily, 3D printing is used by the engineers to create engineering prototypes and has the potentials to enable mass customization of goods on large scale [4]. Earlier, 3D printers were meant for non-tissue engineering purposes [5] but nowadays, these 3D printers are becoming popular for its ability to print porous scaffolds with user-defined geometry, interconnected porosity with controlled chemical properties [6]. The 3D printer interprets the digital supply coordinates derived from the Stereolithography (STL) file format and then converting them to a G-code file through slicing software present in 3D printer [7]. This printing method brings out the freedom to design and fabricate complex structures and enables them to modify, reuse and improve customization [8]. In fields of forensic medicine, creation of models for bone fracture, cardiac infractions and for ruptured organs can be achieved [9]. Every 3D printing technology, adopts a similar process chain, which consists of five steps, they are 3D modelling, data conversion and transmission, checking and preparing, building and post-processing [10]. Unlike traditional manufacturing processes that positioned various constraints on product design, the flexibility of AM allows the manufacturers to optimize design for lean production, by which it eliminates waste that are obtained from the removal of material [11]. It has gained popularity in media and captured the imagination of the public as well as researchers in many fields and customized to a wide range application spectrum such as automotive, aerospace, engineering, medicine, biological systems, and food supply chains [12]. This technological benefits must be linked to the capabilities and requirements of the manufacturing units derived from the business strategy which could be viewed as the market-pull strategy to AM implementation [13]. While the manufacturing constraints for AM are much less

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significant than that of traditional manufacturing methods, there are still emerging possibilities where many of the AM constraints could be better termed as manufacturing considerations, and they do not necessarily constraint the design [14]. Fig. 1 represents the steps involved in 3D printing process from creation of the CAD model to the fabrication of the component.

2. Methods of additive manufacturing

There are essentially seven types of additive manufacturing were present [16]. They are Stereolithography (SL), Fused Deposition Modeling (FDM), Laminated Object Manufacturing (LOM), Selective Laser Melting (SLM), Selective Laser Sintering (SLS), Digital Light Processing (DLP) and Electron Beam Melting (EBM) [17]. In stereolithography parts can be directly fabricated from CAD models without tooling or fixtures. It's a cost effective way of fabrication of 3D structures [18]. Fused Deposition Modeling (FDM) uses a temperature controlled extruder to force out the thermoplastic filament material and deposit the semi-molten polymer onto the platform in a layer by layer process [72]. The monofilament is moved by two rollers which acts as a piston to drive the semi-molten extrude. At the end of each finished layer, the base platform is lowered and the next layer is deposited [19]. In Laminated Object Manufacturing (LOM) technique, a 3D part is built sequentially in a layer by layer from a roll of paper that are cross-hatched completely and act as a disposable base for the part to be fabricated. The roll of paper has a thermally activated adhesive coating on the lower side, and the lamination is accomplished with a heated, stainless steel roller [20]. Selective Laser Melting is being obtained through different powder binding mechanisms [70]. In order to reach high density, the metallic powder particles are fully molten and then fabricated into 3D structures [21]. Selective Laser Sintering (SLS) is a layered manufacturing process that allows the generation of complex 3D parts by consolidating successive layers of powder material on top of each other. The consolidation is obtained by processing the selected areas using the thermal energy supplied by a focused laser beam [22]. Digital Light Processing is similar to Stereolithography that is a 3D printing process, which works on photopolymers [71]. It uses a more conventional light source such as an arc lamp with a liquid crystal display panel, which is applied to the entire surface of the vat of photopolymer resin in a single pass [23]. In Electron Beam Melting process, the raw material, metal powder or wire is placed under a vacuum and fused together from heating by an electron beam [24]. Fig. 2 displays the various classifications in Additive Manufacturing technology. In this article an initiative is being taken to discuss about the impacts of 3D printing in supply chain management and its consequences.

3. Interpretation of supply chain

The controversial claim that reminds as an open challenge to the researchers is the impact of supply chain management in 3D printing and its contribution in manufacturing technology [73]. In general, Supply chain is designated as the network of organizations that are involved through upstream and downstream linkages through the different processes and activities which produce value in the form of products and services delivered to the ultimate consumer [26]. In other words, supply chain is an integrated process where, the raw materials are manufactured into final products, then delivered to customers considering their requirements [27]. Nowadays, interest in supply chain management comprises the planning among various members of supply chain which encompasses the manufacturers, distributors, wholesalers as well as retailers [28]. However, there has been an increasing attention on the performance, design, and analysis of the supply chain. The current interest has sought the extend to include "reverse logistics", to include product recovery for the purposes of recycling, remanufacturing, and re-use [29]. The scope of supply chain begins with the source of supply and ends at the point of consumption [74]. It is much concerned with factors involving supplier management, purchasing, materials management, manufacturing management, facilities planning, customer service and information flow with transport and physical distribution [30]. It is a key factor for the increase in organizational effectiveness and for better realization of organizational goals such as enhanced competitiveness, better customer care and increased profitability [31]. The closed loop supply chain can be established by combining the network of both forward and reverse supply chains [75]. It is essentially meant for the customization of design, control, and operation of a system to maximize the value of creation over the entire life cycle of a product [32]. At present, researches are going on assessing Supply Chain Management policies to a triple bottom line including economic aspects, environmental performance and social responsibility are on process [33]. Higher supply chain velocity leads to the quicker response of market changes or events that helps to improve the speed of recovery from disruptions [34]. Fig. 3 describes the operational process of both supply chain and reverse logistics.

4. Management of supply chain and its consequences

In the verge of understanding the success behind various industries, the interactions between the flows of information, materials, money, manpower, and capital equipment plays a dominant performance. The most momentous revolution in the paradigm of modern business management is the emergence of individual

Fig. 1. Additive manufacturing process [15].

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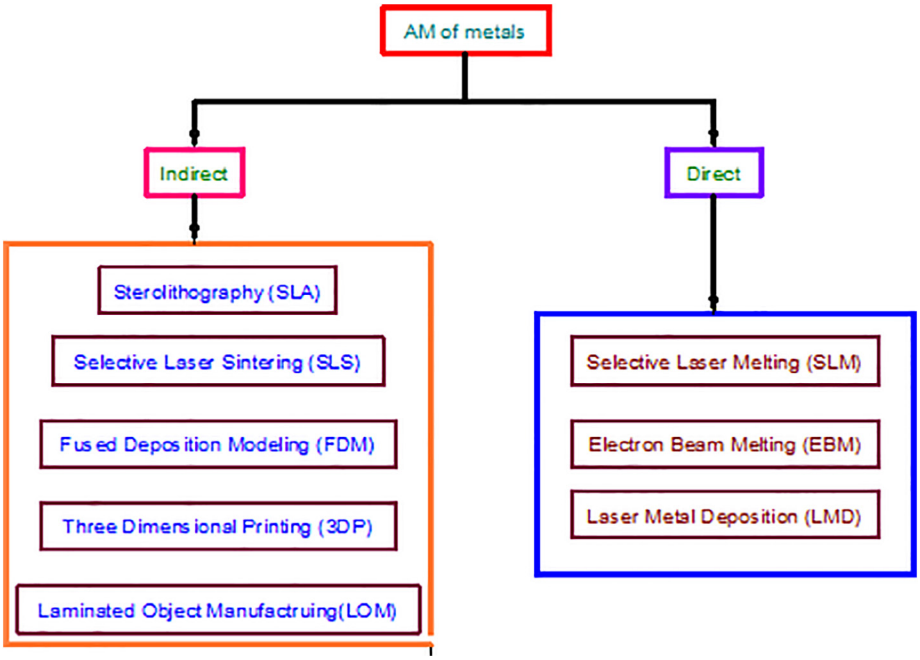

Fig. 2. Classification of additive manufacturing [25].

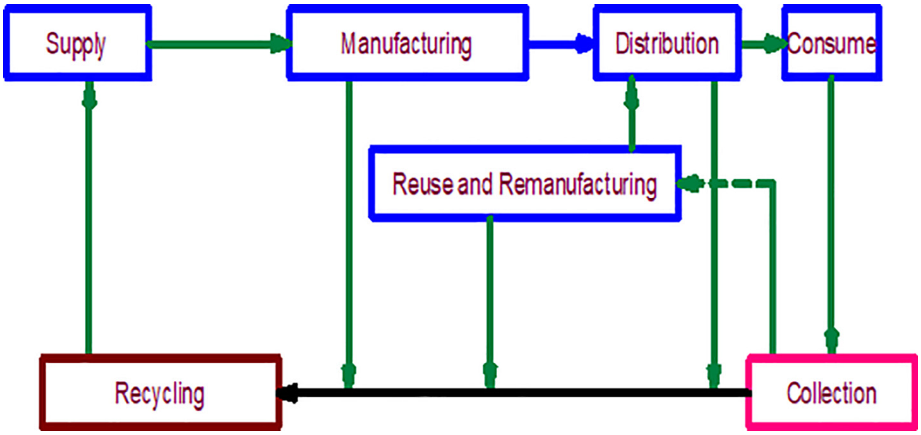

Fig. 3. Schematic representation of Supply chain and reverse logistics [35].

business rather than supply chain mechanism [36]. The main fundamental of supply chain buffered new innovations in production, procurement and distribution [37]. In order to comprehend certain kinds of products aiming at an improved environmental and social quality, "sustainable development" is implemented which can be related to their environmental and social standard [38]. Supply chain management is the assimilation of business process which enumerates value to customers over authentic suppliers [39]. Basic characteristics like inventory management approach, total cost approach, time horizon, mutual sharing, information monitoring, corporate philosophies, supplier base, and flow of information are the essentials of supply chain manufacturing [40]. It also includes the management process of customer relationship which upholds the employment of Product and Sale Agreements (PSA) [41]. Another method of supply chain management is the "green supply chain management" addressing the association between environment and supply chain which has integrated the green-purchasing system [42]. The areas where supply chain management faces the issues are characterized as environmental purchasing, improvement of fuel efficiency, emissions reduction from the transportation equipment, safety in motor carrier, rail, and airline industries [43]. There are enormous sources of uncertainty that plague supply chains, they are supplier uncertainty, arising from on-time performance, average lateness, and degree of inconsistency, manufacturing uncertainty which are arising from process performance, machine breakdown which affects the supply chain performance [44]. Supply chain management focuses on the positioning of virtual organization in such a way that all the contributors in the value chain should be benefitted and the Elective supply chain management rests on the twin pillars of trust and communication that have to be equipped with professional logistics [45].

In the recent work, the link between location planning and Geographic Information Systems is developed and involves the integration of location models into the optimization suite which are developed by the software implementing solutions [46]. It is one of the method to incorporate some of the systemic organizational and inter-organizational implications of the environmental influential policies and its main goal is to improve the green supply chain [47]. The supply chain management practices and performance are influenced by the quality management programs

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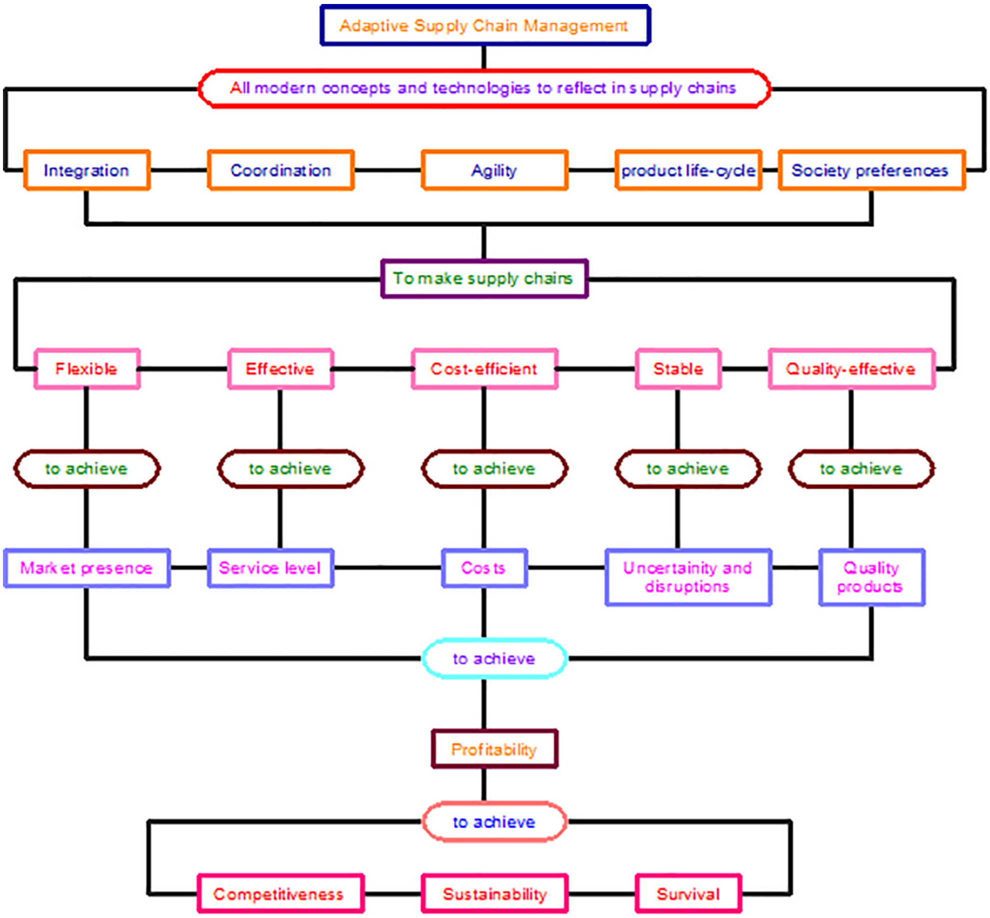

Fig. 4. Adaptive supply chain management [49].

thereby, providing better organizational performances over upstream or downstream relationships [48]. Fig. 4. exhibits the classification of process involved in supply chain management.

5. Impacts of 3D printing supply chain management

The craving impact of 3D printing in accordance with the supply chain management implicates great challenges to the researchers as well as manufacturers. Optimistically, 3D printing paved the contrivance for an “industrial revolution” considered as a “gold rush” that encompass the changes in strategies, competition and industrial geographies in supply chain [50]. The widespread adoption of 3D Printing (3DP) is hindered by numerous decisive factors including high printer acquisition costs, lack of experience with technology and the technical limitations of 3D printers [76]. A typical 3D printing service provides the path for customers to employ the unique combination of design-related as well as manufacturing-related service components to fulfil their vision [51]. The major challenge is to overcome the ability for providing the necessary parts with high fulfilment rates at low costs which can be solved by digital manufacturing technologies and enables the supply chain managers to manufacture any part at any time in different locations and batch sizes without the concern about massive tooling costs [52]. The major strategy in SCM is the Food Supply Chains (FSC) which are the examples of complex supply chains that consist of several inter-dependent steps, like farming, food processing, distribution, retailing and consumer handling [53]. On the other hand, 3D printing can be used by a consumer to download design and then print as a product, and also by the supplier to print highly customized parts [54]. 3DP is cost-effective and has lower manufacturing inputs and outputs in markets with low volume and it has customized high-value production in aerospace and bio-medical component manufacturing [77]. This lowers the usage of energy, resource demands over the entire product life cycle thereby generating shifts towards more digital and localized supply chains [55]. Three-dimensional printing is the best known digital manufacturing technology that has been adopted for a different purpose [78]. More essentially major industrial corporations have established dedicated research centres to support the innovation and widespread adoption of solutions based on digital manufacturing technologies [56]. The additive manufacturing process is infinitely customizable, fast to set up without custom tooling [79]. Hence it creates demand and achieves highly flexible production [57]. Additive Manufacturing technologies have been greatly used in industrial parts production and guarantees the best possible accuracy fit to the customer [58]. The technological evolution that enables local manufacturing through 3DP and has the increased the demand for sustainable solutions and decreased the emission in evolution of “Metropolitan Revolution”, smart city and other societal commodities [59]. Fig. 5 depicts the product flow as well as the information flow directions of the supply chain involving 3D service provider.

6. Assets of 3D printing over supply chain management

The exceptional focus on 3D printing over supply chain management have reached its peak in enormous aspects like minimized production time, cost reduction, less wastage of raw materials, range of quality and design of products according to the desires of customers [60]. It ensures greater possibilities of dig-

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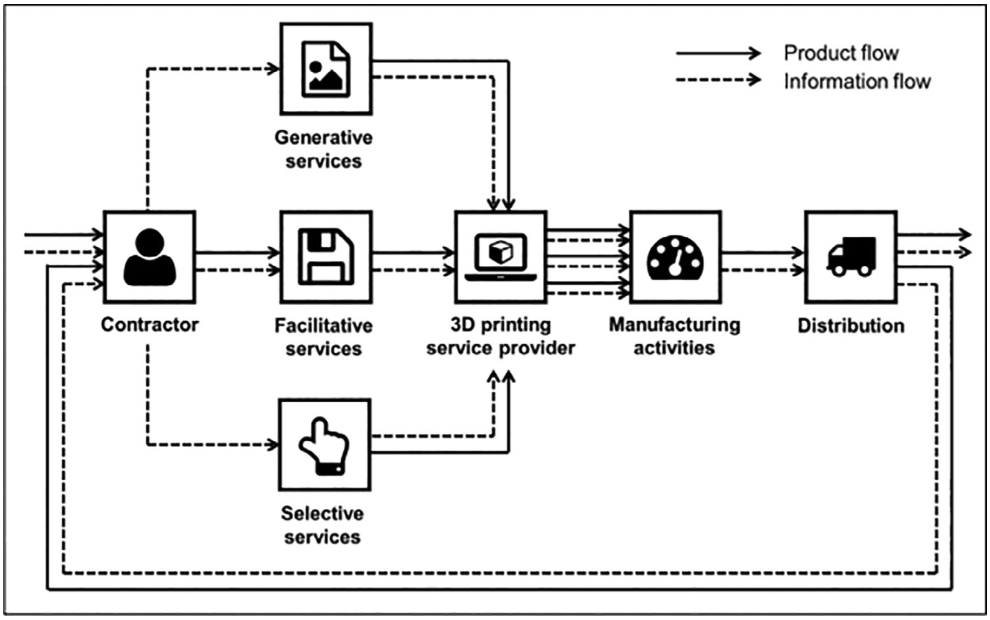

Fig. 5. 3D service provider in supply chain [51].

italization to achieve low cost products in shorter period with improved supply chain dynamics to provide higher degree of complexity in various automotive and aerospace industries [61]. The impact of Additive Manufacturing could be complicated, as it does not only impinge on current methodologies but also on the constituent parts of the supply chain as it requires mainly 3D data and raw material in order to produce a complex part [62]. It paved the way for an industrial revolution which has active involvement of every organization, economy, and society thereby flourishes individuality and creativity [63]. The Additive Manufacturing technology offers new solutions for tooling industries which facilitates the integration of conformal heating and cooling channels in injection molding to maximize thermal management [64]. Additive Manufacturing enables us to design freeform structures without constraints, resulting in less material usage, lower weight, and fewer assembly steps [65]. The commercial users of Rapid Manufacturing are the aerospace industry, where performance requirements often impose stringent quality demands. The rigorous testing and certification are made mandatory to use materials and processes for the manufacture of aerospace components [66]. The development in applications of 3D printing are expanding rapidly, one of these applications that has improved significantly is manufacturing of the “end products” and plays a vital role in the field of virtual reality by creating the virtual fitting rooms [67]. The hybrid processes in manufacturing report proposed the possible future processing pattern. That would combine the 3DP and other conventional modes, including subtractive, transformative, joining, and dividing technology [68]. Fig. 6 shows the various advantages of 3D printing technology in supply chain management.

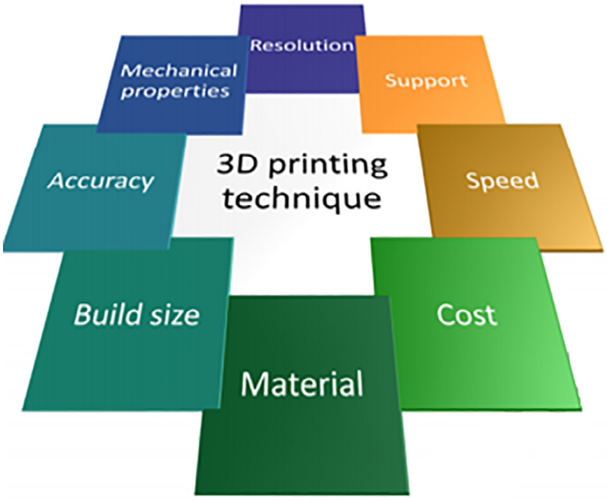

Fig. 6. Influence of 3D printing in SCM [69].

7. Conclusion

Additive Manufacturing is suggested as the best evolving technology in every aspect to revolutionize the facets of living standard and globalization

- The rapid impacts of Additive Manufacturing in Supply chain management incorporates the process of production, definite production time, shortening of materials wastage, elevated flexibility, minimization of production cost, perceptible manufacturing mechanism.
- AM technology is encompassing dominant performance over many industries, including aerospace, automotive, industrial products, consumer products, defense, architecture, and healthcare.
- It affords contemporary opportunities and enhances the possibilities for manifold industries to increase the manufacturing efficiency and streamlines the traditional manufacturing methods.
- This technology has the potential to accomplish a different approach on the way we fabricate the critical components. Thereby, lightweight objects with unique geometries which are capable of reducing the material wastage and consumption of energy can be obtained.

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