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AN IMPLEMENTATION FRAMEWORK FOR ADDITIVE MANUFACTURING IN SUPPLY CHAINS

ABSTRACT

Additive manufacturing has become one of the most important technologies in the manufacturing field. Full implementation of additive manufacturing will change many well-known management practices in the production sector. However, theoretical development in the field of additive manufacturing with regard to its impact on supply chain management is rare. While additive manufacturing is believed to revolutionize and enhance traditional manufacturing, there is no comprehensive toolset developed in the manufacturing field to assess the impact of additive manufacturing and determine the best production method that suits the applied supply chain strategy. A significant portion of the existing supply chain methods and frameworks were adopted in this study to examine the implementation of additive manufacturing in supply chain management. The aim of this study is to develop a framework to explain when additive manufacturing impacts supply chain management efficiently.

KEYWORDS | Additive manufacturing, supply chain strategy, manufacturing strategy, traditional manufacturing, theoretical framework.

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INTRODUCTION

Due to the global economic slowdown, Latin American countries have faced, like other countries, high commodities prices and demand has faltered, particularly from China (de Barillas, 2014). "It has also implied the substitution of locally manufactured goods by imports, affecting the region's manufacturing capacity and competitiveness" (de Barillas, 2014). This opens a timely opportunity for the adoption of new technologies to enhance customization, lower costs, increase value added and improve value chains.

Appleton (2014) stated that improvements in additive manufacturing technology are growing rapidly. Additive manufacturing has been dramatically developed through the past few years to overcome its technical limitations and limited capabilities. However, manufacturers still underestimate additive manufacturing ability to enhance manufacturing processes or business operations, because additive manufacturing is perceived not as cost effective as repetitive processes of traditional manufacturing especially for large scale of production.

Literature shows a significant expansion in the additive manufacturing market. However, it is not easy for top managers to accept the adoption of this technology in manufacturing (Cohen, 2014). That is because the lack of existence of a clear model in literature to show which business strategy best fits the adoption of additive manufacturing, and/or if additive manufacturing is applicable to all types of products and/or how additive manufacturing can change or re-shape businesses and supply chains. Thus, managers are facing some difficulties to implement this technology in their manufacturing system.

Presently, manufacturers are trying to adopt additive manufacturing technology that is characterized by being efficient in energy and material consumption and, at the same time, being very flexible and very fast with regards to:

1. Following the changes in the market demand and
2. Delivering the product to the customer.

The adoption of this technology requires fundamental changes in the applied business models. Changing production systems in manufacturers has to result in the amendment of the business model's operational strategy. Optimizing operations in manufacturers can be done by focusing on enhancing the main elements of operations which are: 1) decreasing costs, 2) increasing quality, 3) reducing both manufacturing required time and lead time, 4) increasing production flexibility and 5) increasing innovation.

Traditionally, companies are concerned with internal performance improvements and keeping intensive works. However, in this globalized market, customers do not really differentiate a company from its suppliers. Thus, companies have to worry about improvements in their suppliers businesses in order to achieve better performance in the market. The performance of one company directly influences others in the same supply chain. Literature suggests performance improvements through additive manufacturing (Cohen et al,. 2014; Wohlers, 2014; Manners-Bell & Lyon, 2012). In addition, literature shows that additive manufacturing affects the supply chain management. Nyman and Sarlin (2014) argued that additive manufacturing is powerful and makes manufacturing processes easier and customization less expensive. Wong and Hernandez (2012) and Ashley (1991) assured that additive manufacturing products are characterized by presenting higher quality, being lighter, customizable, and stronger, already assembled and having lower costs. Conerly (2014) confirmed that very low volume of raw materials and work-in-process will be in inventory, and no finished goods will be stored in stock. Ugochukwu et al. (2012) stated that additive manufacturing technology helps in delivering the right product, at the right time and at the right price to customers. However, they all suggest a great positive impact on supply chain management; additive manufacturing applications are still not fully expanded to cover the supply chain management, so far.

The research problem is focused on the relationship between supply chain strategies and product types. Attention is particularly given to the specific conditions that would make additive manufacturing applicable. It is because there is lack of contextualized, structured and generalized framework that illustrates the best supply chain strategy and product type manufactured that make the adoption of additive manufacturing applicable. The existing literature has limited developments in terms of the conceptualization of additive manufacturing in supply chain management. In addition, previous studies fail in assessing and consolidating supply chain management and additive manufacturing in terms of efficiency of production and responsiveness to market strategies and to link it with the type of products manufactured.

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METHODOLOGY

Due to the exploratory nature of the research, exploratory interviews were adopted in this research.

To better understand the problem, two sets of inductive interviews were held. The first one was conducted with a supply chain optimization consultancy. The aim of this interview is to explore initiatives, practices, problems and guidelines in managing supply chains in general. In addition, to refine the interview questions that were set for the manufacturing companies and to get benefit from their experience in dealing with companies that already adopted additive manufacturing.

The second set of interviews was conducted with three different companies from different industries in several geographical locations. The reason behind this variety is that additive manufacturing became famous in so many fields, such as but not limited to: healthcare, aircraft, automotive, technology, food sector, jewelry, and cloths and footwear.

The criterion followed in selecting the interviewees was based on random sampling. We first checked "All3DP Magazine", a leading additive manufacturing online magazine that ranks the additive manufacturing companies worldwide. Besides, All3DP magazine clusters these companies into different groups according to their geographical areas, industries, printing software, services, etc. From All3DP magazine, we randomly collected contact information of several companies from different industries in different geographical locations and different sizes. Three companies and a consultancy firm specialized in end-to-end supply chain optimization accepted to be interviewed and each suggested a convenient date and time for the interview according to their time schedule. The names of participants and companies are disclosed in the following table (Table 1):

Table 1: Interviewees' General Information

Interviewe	Company	Job Title	Industry	Country	Years of Experience
Fraser Gleekie	FERCO Ltd	Senior Consultant	Supply-chain Consultancy	United Kingdom	40
Michael Lee	Shapeways	Vendor Operations Manager	Consumable products	USA	9
Gabriel Asfour	ThreeAsfour	Partner	Fashion	USA	18
Annalisa Nicola	xybag	CEO and Co-founder	Fashion	Italy	16

The interviews were aimed at exploring the guidelines in managing supply chains and exploring how additive manufacturing is applied in these companies. On the other hand, the interviews helped in pointing out and identifying the relevant elements for designing the conceptual framework for adopting the best fit manufacturing method based on supply chain strategies.

The Proposed Research Framework

A conceptual model of factors influencing the implementation of additive manufacturing technologies as a production method is presented in Figure 1. This conceptual framework has been developed from the literature review and a number of exploratory interviews and it is of a closed loop nature to illustrate the interaction and dependency between the supply chain strategy, manufacturing strategy, and manufacturing method that has to be implemented. Next, the theories that ground our framework are presented and propositions behind the framework are explained in detail.

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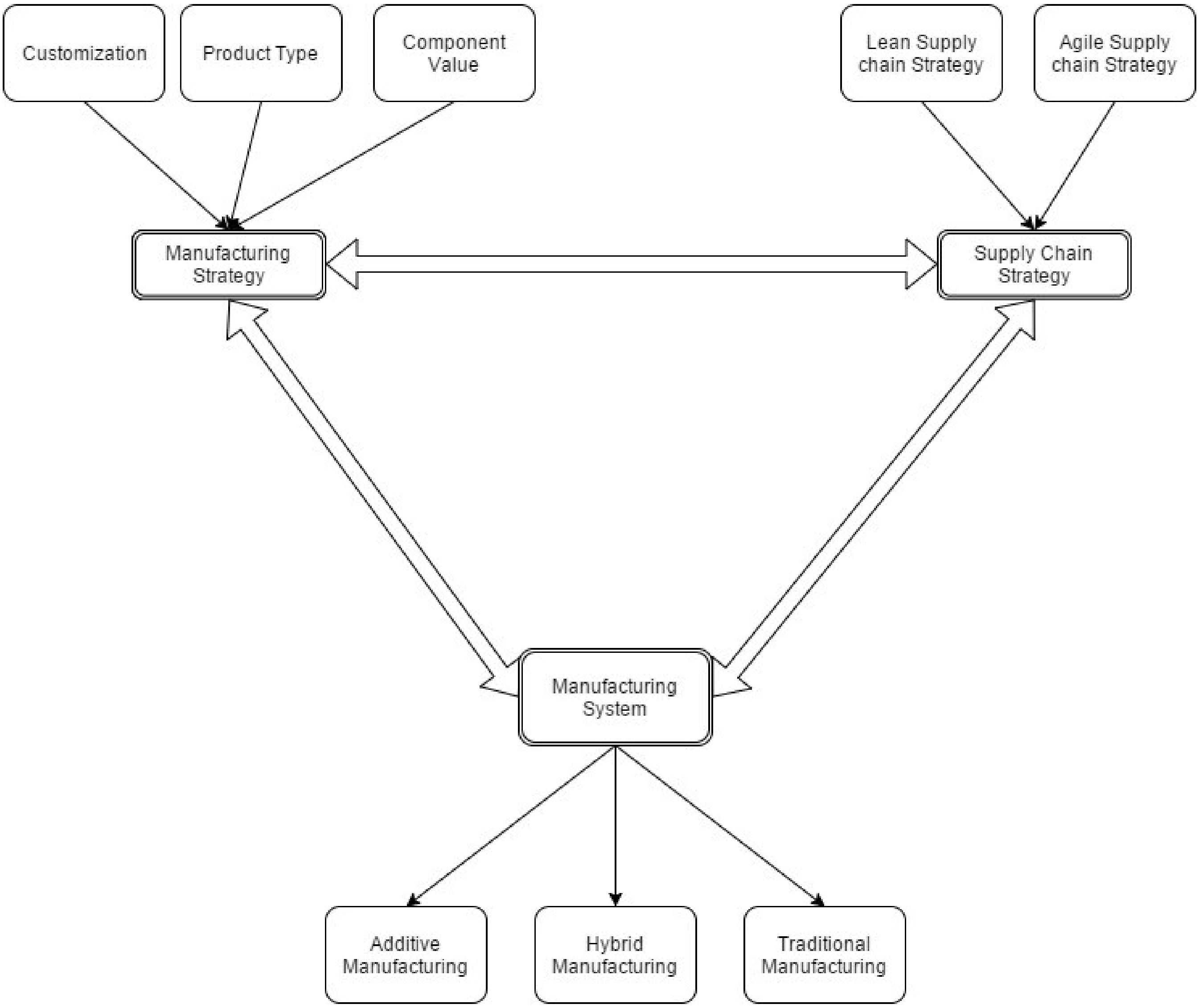
Figure1: Conceptual Framework



Conceptual Framework Basis

The developed conceptual framework is based on the following theories that are discussed in the literature:

Walter et al. (2004) discussed the effect of additive manufacturing on the supply chain. The authors suggest new solutions for supply chain based on both centralized and decentralized applications of additive manufacturing. In other words, they suggest either implementing additive manufacturing technologies on location or to stick with traditional manufacturing method and outsource the production of some parts through additive manufacturing in locations close to customers. They explained the advantages, as well as the disadvantages of both centralized and decentralized application of additive manufacturing. According to Walter et al. (2004) implementation of additive manufacturing on location have the advantage of cutting high inventory costs and cutting production lead-times and delivery lead-times, and overcome of batch constraints. They addressed these advantages to the use of additive manufacturing since "it takes too much time and costs too much to produce the required parts on demand using conventional production technologies". The authors also suggest that decentralized application of additive manufacturing technologies can be used to eliminate these costs. However, the authors were concerned with the problem of having enough demand to warrant additive manufacturing

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machines on location which let the cost of outsourcing much higher in that case. The authors depended on a case study of an original equipment manufacturer operating in the aircraft industry. From their findings, the authors suggest that to maximize the benefit of additive manufacturing, a hybrid system must be applied but concede that centralized application of additive manufacturing will be the first to be used, due to the significant changes the decentralized manufacture will require. Based on Walter et al. (2004) theory, we consider that additive manufacturing technologies are not suitable in all cases. However, implementation of additive manufacturing will definitely reduce the inventory level.

Besides, we also built our framework on Tuck and Hague (2006) theory, which focuses on the cost effective production of customized products. Tuck and Hague (2006) suggests that additive manufacturing increase the customization level, and thus transport costs are reduced and that the burden of part cost will move from skilled labor operating machinery, to the technology and material. This conclusion is supported by Ruffo et al. (2006). Tuck and Hague (2006) also present and explain that additive manufacturing influences supply chains in terms of lean, agile and leagile supply chains. The authors claim that additive manufacturing enhances lean supply chains as the only requirements for producing a product are the design CAD file and raw material. In addition, Tuck and Hague (2006) also suggest that because additive manufacturing can be used for economic low volume production, there is no need to hold stock in inventory. Therefore, a fully JIT system is applicable. They conclude: "Additive manufacturing could offer the first truly leagile supply chain paradigm, providing goods at low cost through the benefits of lean principles with the fast re-configurability and response time required in volatile markets. The production of goods through additive manufacturing could lead to reductions in stock levels, logistics costs, component costs (through reduction in assembled components) and increase the flexibility of production, through the ability to produce products to order in a timely and cost effective fashion." We base our framework on the two supply chain strategies; lean and agile, according to Tuck and Hague (2006) conclusion. Due to the fact that additive manufacturing technologies are being used for the production of personally customized products, our framework illustrates the necessity to understand the strategy employed by the companies, to integrate additive manufacturing and customization.

Conceptual Framework Factors and the Inter-relationship between Them

The key elements of a successful supply chain strategy are the three Vs; Visibility, Variability and Velocity (Walker, 2005). No matter what the specific competitive priority for the organization is, the goal of the supply chain management is to increase the visibility and velocity while reducing the variability (Narasimhan et al., 2008). The three Vs are defined as follows:

- Visibility is the ability to view information in all parts through the supply chain (Narasimhan et al., 2008). Increasing visibility in the supply chain benefits not only the suppliers and/or the partners, but also, and most importantly, the customers. That is because when visibility is increased, managers in the supply chain can react to change or eliminate unnecessary activities that waste resources and thus focus on enhancing the performance of activities that add value to the product.

- Velocity is the relative speed of all transactions that have to be done along the supply chain (Narasimhan et al., 2008). The higher the speed of transactions, the better; it results in a higher asset turnover for stockholders and quick delivery and response for customers. Velocity is similar to visibility; both are enhanced by supply chain management.

- Variability is the natural tendency of the results of all business activities to fluctuate above and below an average value along the supply chain. Variability measures the fluctuation of average values of time to completion, number of defects, daily sales and production yields (Walker, 2005). Contrary to visibility and velocity, variability decreases with good supply chain management. Supply chain management aims to reduce variability as much as possible.

Supply chain should match the degree of demand uncertainty (Fisher, 1997). Implemented strategies of supply chain can be either Pull or Push systems (Cachon, 2004). The push strategy in the supply chain is typically the method used to save customers' waiting time. Ferguson et al. (2002) called this system an "Early- commitment". Adopting this method, companies try to manufacture and deliver products to the shelves before they get orders from customers, in a way to let the final customers find their needs on

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hand. Thus, customers get the product at the exact time when they need it and can immediately have it.

There are three main types of supply chain strategies within push strategy:

1. Stable strategy appropriate for a supply chain which focuses on execution, efficiency and cost performance. With this strategy, only simple connectivity technologies are needed, and real time information is not highly demanded either.
2. Reactive supply chain strategy works well when the supply chain acts to fulfill the demand from trade partner's sales and marketing strategies.
3. Efficient reactive supply chain strategy is the strategy that focuses on efficiency and cost management.

Companies add value to their products in their customers' perspective by saving customer's time of waiting to satisfy their needs. However, push strategy could not be perfect for all types of products and that is because one critical point is missing in this approach. Customization has not been taken into consideration. Innovative and, sometimes, functional products need to be customized according to customers' preferences. Push supply chain does not give the customers the opportunity to customize their goods. However, pull supply chain is the preferable strategy in such cases. Pull supply chain allows the customer to ask first in order to manufacture what he/she wants, and then the product is delivered to them (Iyer & Bergen, 1997). Applying this strategy, however, makes customers wait for some time to get what they ask for.

Additive manufacturing implementation in a supply chain provides the ability to enhance supply chain efficiency and effectiveness in terms of cost reduction, and time saving (Tuck & Hague, 2006).

Even "Efficiency" and "Productivity" terms are sometimes used interchangeably, as in Sengupta (1995) or in Cooper et al. (2000). However, in this research we differentiate the definition of efficiency from productivity. Based on our understanding of the literature, "Productivity" is defined as the ratio between outputs and inputs. While, "Efficiency" is defined as the proximity of a focal organization to its benchmark within its cluster or industry depending on:

1. The minimum cost of production in manufacturing and delivering a final product to a final individual consumer, and
2. The velocity of the supply chain when transforming inputs into outputs and delivering the final product to its final customer. The manufacturing velocity is defined as the ratio of the value added to the total throughout time.

In manufacturing, managers should think about the two main cost drivers: direct and indirect costs, which are summarized in material, labor and overhead. At the same time, they should think about producing goods to satisfy customers' needs. In that sense, an ideal product is one that consumes the least direct and indirect costs of material, labor and manufacturing overhead and, at the same time, satisfies customers' needs and wants (Sun, 2011).

Sun (2011) argues that in order to create a firm uses the minimum possible inputs to produce the maximum possible value for customers, efficiency tool is needed. In his opinion, lean production is that efficiency tool.

In order to be efficient in delivering the right product that satisfies customers' needs, Value Specification suggests that all non-value adding activities have to be eliminated from the process (Gupta & Wilemon, 1990). Eliminating unnecessary steps will accelerate the speed of production process while using fewer resources and so improving both effectiveness and efficiency (Iansiti, 1995b). In addition, Value Stream helps to visualize the sequence of activities in the whole process, thus making it easier to identify and eliminate non-value adding activities. This ensures increased efficiency.

Moreover, many authors, such as Sun (2011), Iansiti (1995a,b), Cordero (1991), Gupta and Wilemon (1990), Rosenau Jr (1988), and Gold (1987) have agreed on the basic idea of increasing and improving efficiency through lean management, which refers to the elimination of non-value adding activities. Therefore, working on purely value adding activities in less time, and with less resources, improves and increases efficiency.

Besides that, and based on what has been discussed earlier, we conclude that lean production is recognized as an efficiency tool, because it focuses on producing outputs with minimum cost by using the least possible resources to deliver products that have the maximum possible value for customers. As con-

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sequence, lean production creates firms seeking to add value to their products in all possible ways (Sun, 2011); which means that lean must not be for indoor use only. It must be widespread across the entire process, starting from getting raw materials and continuing until the product is in customers' hands. It means that lean should go beyond production to reach the entire organization, including the supply chain. In that sense, firms that go beyond production in implementing lean thinking can be termed Lean Corporations, which is a more accurate concept to be used (Sun, 2011). Moreover, their activities could be acknowledged as a lean value chain.

In a lean value chain, manufacturers identify each activity to check whether it adds value or it is unnecessary and can be removed. Through lean techniques, managers encounter dispensable activities that create costs and eliminate them. For instance, the JIT technique permits manufacturers to avoid superfluous costs of shipping, receiving, inspection and rework (Sun, 2011).

What is more, lean value chain elevates manufacturers' flexibility in pursuing the market's changes due to demand uncertainty and changing customers' tastes and preferences. JIT lean tool allows firms to change outputs more quickly in response to demand changes, compared to other manufacturing methods.

Lean management is the main bridge that links additive manufacturing with supply chain. Lean management serves as a great linkage that connects both topics by focusing on the efficiency of production. Companies' success or failure depends on getting the right product at the right time, and at the right price to customers (Nyman & Sarlin, 2014). As was clearly visible when reviewing lean management and additive manufacturing literature, both share the following two characteristics:

1. Eagerness to increase efficiency. Many authors, such as Sezen and Erdogan (2009), explained lean as a method used to reduce costs, as well as to increase efficiency and quality. Moreover, Shah and Ward (2007) defined it as a management philosophy. Their definition was perfectly positioned on clear identification and elimination of wastes not only within, but over and above the production process to reach the whole manufacture's product value chain. Nevertheless, from all the reviewed literature, we concluded that all researchers agreed upon one main opinion in defining the objective of lean concepts. This objective is summarized in cost reduction and production efficiency improvement. In addition, researchers and authors in the additive manufacturing field agreed that additive manufacturing methods are able to cut down manufacturing costs and save time. Based on literature review, Wong and Hernandez (2012) proved that additive manufacturing is able to depreciate costs and save time. This has been stated by many other researchers such as: Noorani (2006), Herbert et al. (2005), Cooper (2001) and Ashley (1991). Cost reduction and time saving form the basis of doing things right in terms of what is known as "efficiency."

2. Better responsiveness to market changes in both demand and supply. Globalization and openness to the entire world's markets create rapid changes in natural conditions, technological progress, transport improvements, customers' income, customers' tastes and preferences, and future expectations of both customers and suppliers. In this sense, lean management uses practices and techniques that make the manufacturing process very responsive to these changes (Mohanty et al., 2007; Nightingale, 2005). "Right amount at the right time" practice, "Pull System" tool and "JIT" tool are methods that technically enhance responsiveness to changes in the market. These methods are based on having low amount of raw materials inventory, as well as, work-in-progress and finished goods. Low inventory levels facilitate adapting to new changes in the market easily with minimal inventory costs. Moreover, additive manufacturing is based on producing small production runs pulled from customers' needs, in contrast with traditional manufacturing (Campbell et al., 2011). This feature in additive manufacturing gives it the advantage to be able to quickly adapt to market changes by not holding high levels of inventory on hand.

Based on our previous discussion, we concluded that additive manufacturing has features that makes it able to work well with lean strategy in the supply chain, where it fits perfectly under the following principles:

1. Value Specification: Specifying value, from the end customers' view, involves trying to find out what customers desire from the product (Womack & Jones, 1996a). Thus, in order to

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specify the value, a lean practice of realizing customers' needs has to be applied. In that sense, a lean tool has to be put into action in order to translate customers' needs into tangible product. Here additive manufacturing plays a role in transforming the specified value of customers' needs into real products (Nyman & Sarlin, 2014; Wong & Hernandez 2012) because additive manufacturing is a very flexible production tool. Products can be produced to meet customer's exact requirements for the product. Materials used, shapes, sizes and any other features can be adjusted on the spot to meet what the customer requires, with minimal costs of production compared to traditional methods.

2. Identifying Value Stream: Organizations must identify value stream of products at every step of the supply chain, in order to enhance the value added activities and eliminate the non-value adding ones from the process (Womack & Jones, 1996b; Womack et al., 1991). When companies identify the value stream in their supply chain, they will be able to reduce costs which are synonymous with waste (Shah & Ward, 2007; Ohno, 1988). Additionally, additive manufacturing has proven its effectiveness in reducing costs to the minimum by reducing waste from production (Berman, 2012; Sealy, 2012). On that account, additive manufacturing could serve as an effective lean tool to produce and deliver products that hold the maximum value to customers with minimum wastes and costs.

3. Pull Principle: Womack and Jones (1996a) explained the pull principle as "production should be done only when customers demand the product." That consecutively explains the Right Amount at the Right Time practice in lean management that calls to produce the needed quantity only when it is needed (Shah & Ward, 2007) because excess in production leads to higher costs in inventory. Based on these principles and practices, we can presume that additive manufacturing perfectly performs the needed duties to be a proper tool in lean management. Based on the fact that additive manufacturing makes it feasible to produce any product required by customers, at the time it is demanded, without the need to change production process or change or retrain personnel as is often required with traditional machinery. In addition, it allows for product differentiation and customization, because of its ability to flexibly produce any size or shape required (Sealy, 2012).

With additive manufacturing, both customers and businesses can benefit from designing and personally customizing their final products. This new technological manufacturing method makes it possible to modify the functionality of a product, from one side, and physically from the other, in order to fit the needs of the customer, in a way that was not available before. This, of course, has affected the supply chain. Businesses should keep pace with these changes and keep modifying their supply chain to fit the new requirements of the market.

Literature has showed that supply chain is not fixed for all types of products or all types of businesses. Supply chain differs from one production line to another to match the uncertainties in both demand and supply (Lee, 2002). Some businesses are looking to shorten the supply chain by eliminating some activities, while others are interested in having a responsive one and others like to hedge the risks stemming from either supply or demand uncertainties.

When additive manufacturing is applied, the supply chain takes a different shape. This is because traditional manufacturing methods depend mainly on mass production, where products are made in batches and stocked in inventories and have to be distributed to wholesalers and retailers in order to arrive to final customers. With additive manufacturing, responsiveness and the flexibility of both customization and delivery is more easily achieved while eliminating all non-value adding activities such as inventory and distribution.

Lee (2002) argued that agile supply chain is a strategy that makes the supply chain capable of quickly responding to changes in the market and in customer preferences, and diversify the product's functionality to perfectly match customers' needs. In the context of additive manufacturing, agile supply chain is the strategy that is qualified to deliver a perfectly customized product to customers, with the most efficient mode of delivery, at a minimized cost; this is achieved by cutting all unnecessary activities that add no value to the product. In addition, agile supply chain is capable of responding quickly to any changes in customers' preferences while risks are minimized.

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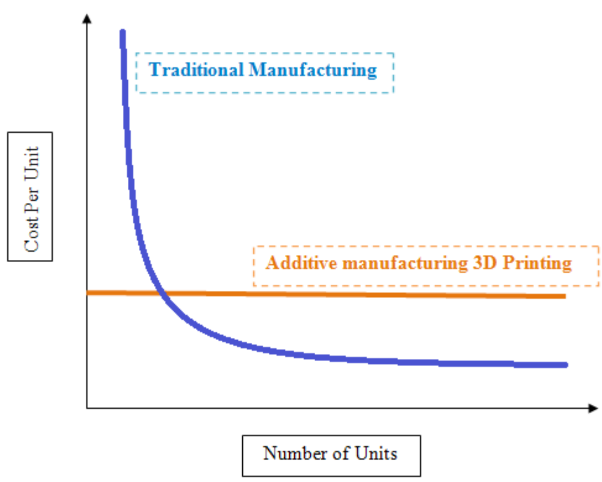
Thus, agile supply chain combines the characteristics of efficiency, responsiveness, risk-hedging and customization. Likewise, additive manufacturing is based on the same characteristics, while responding to customers' requirements and perfectly customizing products to fit their needs, cutting costs by reducing waste and eliminating non-value adding activities. In this fashion, implementing additive manufacturing in focal organizations of the supply chain requires the supply chain to take the shape of an agile supply chain.

Previous studies found that technology has the ability to change and reshape businesses as well as implemented strategies (de Jong & de Bruijn, 2014). It is considered to be an internal strong point of the business SWOT analysis when businesses know how to properly employ these technologies to bring opportunities to their side. However, based on the held interviews, interviewees such as Asfour from Three-Asfour and Gleekie from FERCO LTD, claim that additive manufacturing cannot be implemented in businesses to produce all types of products and/or all product components. They suggest that additive manufacturing is more feasible when it is used with high valued components or for complex products.

Additive manufacturing has been applied to low-volume production, and the output can be of higher rank than that of the traditionally manufactured output; that is, additive manufactured products (especially consumer goods and health aids) are characterized by presenting higher quality, being lighter, more customizable, stronger, already assembled and having lower cost (Wong & Hernandez, 2012; Ashley, 1991) than items produced by traditional manufacturing methods. Additive manufacturing has the ability to precisely control the quantity of material used to make the product.

Nyman and Sarlin (2014) argued that additive manufacturing is powerful and makes manufacturing processes easier and customization less expensive for customers. In traditional manufacturing methods, managers forecast future demand. Based on that forecast, a sufficient amount of outputs, that is in accordance with the management's forecast, is produced and stocked in inventory (Lee & Billington, 1992). However, when additive manufacturing is implemented in a manufacturing method, real-time demand manufacturing is set in motion. This feature in additive manufacturing results in shorter lead time from order to delivery and it gives the supply chain more flexibility in responding to changes in product demand. Additive manufacturing allows manufacturing to become more agile, more flexible, abler to respond rapidly to shifts in market demand, and more capable of introducing new products quickly and inexpensively. As a result, both manufacturing and consumer behavior are affected. It also affects the supply chain; it accelerates the shift from "Push Supply Chains" to "Pull Supply Chains." This is because additive manufacturing makes it possible to store products, parts and components on computer files, with no need to have them physically in warehouses. Each component can be pulled only at the time it is needed. Contrast this with the JIT lean management tool that let managers keep some inventory on hand in warehouses to avoid the risk of shortage (Conerly, 2014). Thus, a very low volume of raw materials and work-in-progress will be in inventory, and no finished goods will be stored in inventory (Conerly, 2014). As a result, overall supply chain management costs will be lower than those of traditional manufacturing supply chains, because of the reduced inventory costs and the reduced waste of outdated products. However, the production cost per one unit in traditional manufacturing methods, where production runs for huge batches, is much lower than in additive manufacturing (Conerly, (2014). Conversely, the opposite is true for small production runs; cost per unit in additive manufacturing for small batches is relatively low when compared to traditional manufacturing. Figure 2 is a hypothetical graph that explains the difference between production cost per unit when using additive manufacturing methods and traditional manufacturing methods, with reference to number of units produced in each method.

Figure 2: Hypothetical Cost per Unit in Both Additive Manufacturing and Traditional Methods of Production



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Additive manufacturing has the ability to personalize products to the customer's preferences. Additive manufacturing gives manufacturers the ability to be flexible in creating products based on each customer's requirements (Sealy, 2012; Wong & Hernandez, 2012; Gibson et al., 2010). Thus, in some industries, this manufacturing method delivers a perfectly customized product to customers, which, in turn, is reflected with higher customer satisfaction (Wong & Hernandez, 2012); Noorani, 2006).

In that sense, with additive manufacturing, both final customers and businesses can benefit from designing and perfectly customizing or even personalizing their final product; as is the case in some companies such as Shapeways and XYZBags. This new technological manufacturing method makes it possible to modify the functionality of products, on one hand, and the physical appearance of products, on the other, in order to fit the needs of the customer in a way that was not available before. This, of course, has affected supply chain management. Businesses should keep pace with these changes and continue to modify their supply chain in a way that fits the new requirements in the market.

As a conclusion, cost reduction in manufacturing mixed with fast responsiveness, flexibility and customization make it easier for focal organizations to gain a competitive advantage in the market. That happens due to the ability to reduce prices for final customers, customizing the product to the final customer's preferences and expediting the delivery of products. As a result, customer satisfaction increases. Thus, as a result of increasing agility, flexibility, responsiveness, cost-efficiency, customization and customer satisfaction, the overall profitability of the entity will be increased.

FINAL VIEW OF THEORETICAL FRAMEWORK

Global competitiveness increases the complexity in all activities and processes in any business corporation. Business firms must clearly understand and know how to apply strategies in such a competitive market. Supply chain management is one the most frequent approaches in this global competitiveness. Mabert and Venkataramanan (1998) argued that managing all the activities in the supply chain has become more challenging. That explains why practitioners and researchers paid more attention to this field. Likewise, firms have to strategically manage their supply chain in harmony with the type of products they produce in order to be effective and thus achieve higher financial and operational performance (Christopher & Towill, 2000; Fisher, 1997).

Literature suggests two main strategies for the supply chain: efficiency in production strategy, which is also called lean strategy and responsiveness to market which is also known as agile strategy (Bruce et al., 2004; Yusuf et al., 2004; Christopher, 2000; Christopher & Towill, 2000; Fisher, 1997). Moreover, researchers in supply chain strategies are highly interested in studying the product's type. Based on Fisher (1997) framework that suggests an alignment between supply chain strategy and the type of product manufactured, we proposed our theoretical framework. However, Fisher's framework proposes the two supply chain strategies and attached each of them to one type of product; in our framework, product's type depends on the complexity of the product. We adopted the definition of product complexity from Novak and Eppinger (2001). The authors argue that product complexity depends on the production required knowledge, the difficulty to learn how to produce the product and the required time to produce one unit of the product.

Figure 3 presents the theoretical framework which is basically based on Fisher's (1997) framework. It suggests two fundamental supply chain strategies as in Fisher's: 1) efficiency in production strategy, 2) and responsiveness to market strategy.

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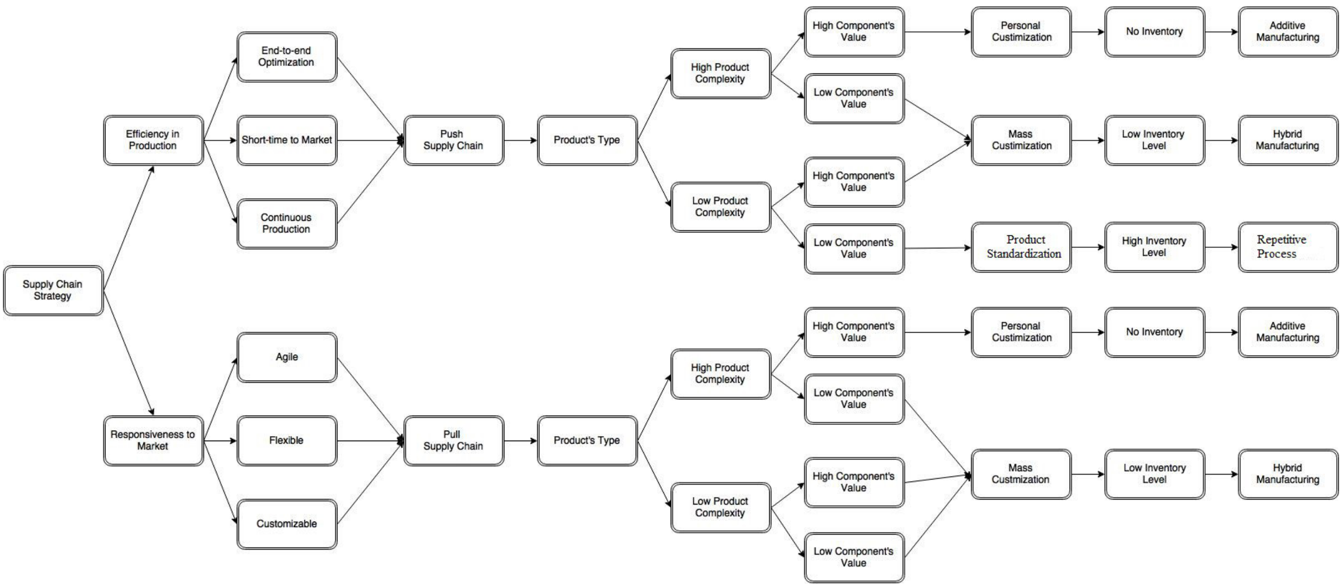
Figure 3: Theoretical Framework



Efficiency in production strategy is characterized by end-to-end optimization, short-time to market and continuous production. Efficiency strategy involves lean production which means eliminating all kind of wastes to reduce cost to the minimum (Womack et al., 1991). Lean production strategy requires a stable product demand which makes it easier to reduce wastes through optimizing end- to-end activities, such as the level of work-in-process and finished goods inventory. In addition, the optimization of the activities creates a stable and continuous production schedule which shortens the lead time, as well. Thus, the main goal of lean production is to reduce cost and increase efficiency by eliminating wastes (Womack & Jones, 1996b). Along these lines, in a stable product demand environment, push supply chain strategy best suits the efficiency in production strategy. On the other hand, responsiveness to market strategy is characterized by agility, flexibility and customization. It provides the business firm with competitive advantage in a rapidly changing environment through offering unique customized features to customers. Rapid changes in customers' tastes and requirements have let the supply chain to respond and act faster in providing the required goods. Agility has got much attention in the literature. Researchers, such as Kidd (1995) have proposed agility as a tool to gain competitive advantage in a dynamic environment. Others have explained it as "the successful exploration of competitive base" (Yusuf et al., 1999). Agility means fast responsiveness and flexibility in responding to customers' requirements. It requires innovation pro-activity and offers higher quality products. Thus, agility is not limited to a single business firm, but it is expanded to cover all the supply chain (Christopher, 2000). While Christopher (2000) argues that agile supply chain reduces the lead time, Lee (2004) suggests that agile supply chain has the ability to respond faster and more easily to changes in a very short time. Thus, this discussion leads business firms to adopt pull supply chain strategy when the market environment is changing rapidly. Due to the fact that pull strategy is able to respond faster to customers' requirements, it is also able to customize the commodity to their preferences. In general, researchers agreed that firms producing functional products better fit with efficiency in production strategy and thus need push supply chain, while companies that produce innovative products need responsiveness to market strategy and so pull supply chain works better to them.

When the manufacturer decides which strategy to use, the first step is to check the product's type. Products can be classified by their complexity; either high complexity products or products with low complexity. The main element that affects the selection of supply chain strategy is the product's type (Huang et al. (2002). As mentioned before the product complexity depends on the production know-how and the time needed to learn the production process, in addition to the time needed for production (Novak & Eppinger, 2001). After clarifying the product's type, the components value should be recognized. The value of the product's components can be either high value or low value, as well. Products that are combined by high val-

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ued components are the ones that can be better customized. In this case, when the components' value is high and the product's type is characterized by high product complexity, personal customization better suits the production method. Thus, dramatically low or even no inventory is required for final goods. However, customization raises the production cost in the tradition manufacturing method. So, additive manufacturing method would be the appropriate method to be used in such cases. On the other hand, when the product is characterized by low product complexity and it is produced by low components' value, mass production and/or mass customization are the best production strategies to be used in this case. As a result, high inventory levels of finished goods will be on hand. Moreover, it is more feasible to use the traditional manufacturing method with low investment in additive manufacturing for prototyping purposes or for the production of some components, only.

CONCLUSION

There have been very few studies focusing on the study of additive manufacturing implementation, and no specific research has focused on supply chain strategies or product types to describe the feasibility of additive manufacturing implementation. In the identification of the research problem in adopting additive manufacturing technologies, the research problem highlights the lack of additive manufacturing implementation studies in the literature, specifically highlighting that top managers face difficulties and the fear of taking the decision of implementing new technologies in the manufacturing process. Nevertheless, there is a high need for lowered cost customized products in Latin American countries, which could grasp the opportunity of the globalized economy's slowdown. As was highlighted in the introduction of this study, additive manufacturing technologies are not successful to all manufacturing businesses. Thus, this study has provided some insight into when firms should implement additive manufacturing as the only production method and when it should be a complementary method to the traditional one based on some characteristics in the product itself and in the management of the supply chain.

In this research, we focused on operative characteristics of supply chain strategies to grab the opportunity of implementing additive manufacturing as an appropriate production method. This study contributes to the field of additive manufacturing research by offering a framework that explains the conditions that make the implementation of additive manufacturing feasible in supply chains. The framework describes two possible supply chain strategies and links each of them to the product types and the value of the product's components to end up with the feasible manufacturing system. Latin American manufacturers can rely on this framework to enhance their supply chains and add value to their manufactured goods.

Our theoretical framework suggests that additive manufacturing can be implemented if the firm is adopting efficiency in production or responsiveness to market supply chain strategies. However, additive manufacturing technology is not always the best manufacturing system to be used when it comes to the product type and the value of its components. Thus, our framework recommends implementing additive manufacturing when the product is complex and is formed by high value components.

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