# Additive manufacturing technology driving supply chain innovations in small and medium-sized firms

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## Abstract
Additive manufacturing (AM, 3Dprinting) means novel manufacturing technologies and the use of digital models to build up an object additively, making it fundamentally different from subtractive manufacturing. This novel manufacturing approach does not concern only technologies, but it also has implications on the firms' supply chains. Supply chain innovations related to AM deserve further research, particularly among small and medium-sized firms (SMEs). This exploratory interview-based study reveals practical changes in supply chains and requirements for AM-driven supply chain innovations in SMEs. To be leveraged fully, AM needs complementary supply chain innovations in the business processes, technology and structure.

**Keywords:** Additive manufacturing technology, supply chain innovation, SME

### Background and purpose
Additive manufacturing (AM) implies the use of digital product designs and a process of joining and adding material, usually layer by layer (ASTM, 2012), to produce goods. It is an ongoing industrial change that can challenge the traditional removal and molding-centric manufacturing and, thereby, either revolutionize entire manufacturing processes (D'Aveni, 2015; Weller et al., 2015) or complement traditional manufacturing (Rylands et al., 2016; Holmström et al., 2016). Earlier conceptual studies show that AM has a great potential to enhance operations through a variety of benefits (e.g. Holmström et al., 2010; Weller et al., 2015). A majority of previous research has focused on AM in large early adopter firms, whereas less is known about small and medium sized enterprises (SMEs) and the possibilities with AM more broadly in supply chains. Supply chain innovation is a possibility for manufacturing firms to maintain and enhance their supply chain competitiveness. It means a change within a supply chain network, technology, process, or their combination that pursues new value creation for the stakeholders (Arlbjørn et al. 2011, p. 8).

This paper focuses on the supply chain innovations concerning AM in various companies' supply chains. AM can have a significant effect on the manufacturing firm's supply chain (Bogers et al., 2016; Holmström & Partanen, 2014) and potentially require the re-engineering of business logics (Weller et al., 2015). Manufacturing firms' supply chains involve various

companies and it is not, yet, clear which firms in the supply chain should implement AM, how their partners can support AM adoption, and what kinds of structures emerge for AM supply chains (Rogers et al., 2016).

According to European commission (2009), small and medium-sized enterprises (SMEs) are companies that employ fewer than 250 people and their turnover is below 50 million euros. Evidence from the previous studies show that SMEs differ from large companies concerning innovations especially by being risk aversive in innovation activities (Lasagni, 2012), lacking systematic development processes (Tovstiga and Birchall, 2008), and, on the other, hand having a greater capacity to absorb new knowledge and technologies (Vossen, 1998). AM-specific studies are expecting that SMEs' role in the future may be considerably high (Rogers et al., 2016; Sasson and Johnson, 2016). Therefore there is a need to increase knowledge of supply chain innovations for the different AM adopters, particularly SMEs.

The purpose in this study is to explore the SMEs' perspective to supply chain innovations driven by AM. The goal is to create knowledge on alternative AM supply chain innovations and the related strategic decisions in SMEs. The research questions are: *1) What types of changes do SME managers anticipate from AM in their supply chains? 2) How can SMEs leverage AM through innovations in their supply chains?*

This study, thereby, focuses empirically on SMEs; large firms are purposely excluded. We acknowledge the multiple types of SMEs in the manufacturing firms' supply chains: OEMs, subcontractors, service providers, and industrial designers. Material suppliers (metal-powder) are not included. We take an exploratory approach and have studied the issue in a qualitative, interview-based design in one country.

The paper continues by reviewing previous research on supply chain innovations and impacts of AM to supply chain. We then introduce the exploratory research approach and interview data. The findings include a categorization of AM driven supply chain changes and required innovations across the different types of SMEs. Then, the contributions are discussed and concluded.

## Literature review

Manufacturing firms seek ways in which they can enhance their efficiency and profitability. One of such ways is considering completely new manufacturing technologies, such as AM. AM has been experienced as a potential way for economical small scale production batches, design changes and waste reduction (Holmström et al., 2010). There are indications that a single firm cannot reach the benefits of AM alone, but that its implementation requires involvement of multiple stakeholders in the supply chain (Oettmeier and Hofmann, 2017). Supply chain in this study is defined as a chain formed by companies where materials and information are transferred and processed between the companies to create value (Heikkilä, 2002).

### *Supply chain innovations*

Manufacturing firms operate in chains or networks of companies that need to collaborate to produce a product or a service. Supply chain innovation can be defined as "a change (incremental or radical) within a supply chain network, supply chain technology, or supply chain process (or a combination of these) that can take place in a company function, within a company, in an industry or in a supply chain in order to enhance new value creation for the stakeholder" (Arlbjørn et al. 2011, p. 8). Supply chain innovation is a possibility for manufacturing firms to maintain and enhance their supply chain competitiveness.

Different kinds of supply chain innovations are possible. Innovations can be divided into incremental (usually optimization) or radical (completely new) changes (Freeman & Soete, 1997), and the classification depends on the experiencer (Johannessen et al., 2001). Concerning the location, innovations can be divided into intra-organizational (innovations implemented within a company e.g. new planning system for the firm's own use) and inter-organizational innovations (implemented within two or more participant firms e.g. advanced open planning system that may cover a two or more firms in the manufacturing chain) (Santosh & Smith, 2008) and they must aim for creating new value (new products, new services and new network structures) (Arlbjørn et al. 2011).

Supply chain innovations have been conceptualized to consist of three elements: 1) supply chain business processes, 2) supply chain technology, and 3) supply chain network structure (Arlbjørn et al. 2011). Supply chain innovations can originate from any of the three elements or they can be a composition of two or all three of the elements (Munksgaard et al., 2014). Examples of innovations in supply chain business processes deal with changes in customer relationships or service management, demand management, or order fulfillment, and they often deal with activities in-house or with customers and suppliers. Examples of innovations in supply chain technology can include enterprise resource planning systems or other advanced planning systems, and they often incorporate information systems and technologies harnessed for the use of a supply chain. Examples of innovations in supply chain network structure may take place in terms of insourcing and outsourcing, partnerships, collaborating and logistics, and they may change the depth and width of the upstream and downstream relationships and roles in the supply network. (Arlbjørn et al. 2011; Munksgaard et al., 2014)

*Supply chain aspects of additive manufacturing*

Supply chain innovations have not been covered purposely in AM, but indications of such innovations can be found in some previous studies. Most of the previous studies are conceptual and have covered the possible impacts that the implementation of AM will have on supply chains (Holmström et al., 2010; Petrick and Simpson, 2013; Bogers et al., 2016; Ford, 2014; Glasshroeder et al., 2015; Steenhuis and Pretorius, 2017). Only a few empirical studies take supply chain impacts into consideration (Rogers et al., 2016; Rylands et al., 2016; Thomas, 2016), and these typically emphasize the viewpoint of large firms or a single SME.

The implementation of AM machines occurs between two supply chains: the first supply chain is from the machine supplier (also raw material suppliers) to the purchaser, and the second supply chain concerns the AM manufacturing firms' customers and other suppliers (Mellor et al., 2014). In the previous conceptual studies, AM has been considered as a possible way to improve manufacturing firms' supply chains or supply chain position. The nature of AM (e.g. possibility for product-level integration that may reduce the need for multiple part assemblies) creates the potential for simpler supply chains, shorter lead times and lower inventories, which most likely will result to cost reductions (Holmström et al., 2010; Glasshroeder et al., 2015). On the other hand, to achieve cost reductions, supply chains need to be flexible, simplified or compressed (Flores Ituarte et al., 2016). Because AM relies completely on digital designs, it is likely that some sections of the supply chains that formerly focused on physical components will transform to being fully digital (Campbell et al., 2011). An example of this could be a part that consisted of multiple components that needed to be assembled, and with AM this complete part can be manufactured at once based on a digital model. This shift to single-step parts manufacturing will likely reduce the physical

transportation needs in supply chains (Birtchnell and Urry, 2013), which will have an impact on inventory and logistics costs (Holmström et al., 2010; Holmström and Partanen, 2014; Mohr and Khan, 2015) as components can be manufactured and procured on demand.

Full customization and faster product development through AM (Hopkinson et al., 2006; Berman, 2012) will have an impact on time-to-market (Petrovic et al, 2011). There is also a possibility for getting rid of the economies of scale and moving into "economies of one", and this will allow companies to move from high to low volume production without cost penalties (Holmström et al, 2010; Sasson and Johnson, 2016). Some production features in the current AM technologies need to be taken into consideration, to reach the volume-related benefits from AM. In AM technologies, manufacturing capacity does not deal with the number of components but, rather, the building platform fill rate, meaning the degree of filling the platform where a component is then grown. This means that ultimately batches of one may not be economically feasible if the component is much smaller than the building platform (Piili et al., 2015). These impacts enable firms to change the manufacturing location closer to the customer need (Holmström et al., 2010; Petrick and Simpson, 2013), which creates the expectation that outsourcing to low labor-cost countries would decrease (Campbell et al., 2011).

In the empirical studies it has been found out that AM is a rapidly emerging industry where service providers are taking a foothold (Rogers et al., 2016). AM is complementing traditional manufacturing by creating new different value streams with product customization (Rylands et al., 2016). AM is a method of producing small batches cost-effectively, where AM is the most expensive phase, whereas assembly and logistics costs are lower than in traditional manufacturing (Thomas, 2016).

Many of the benefit expectations of AM, indeed, build upon the assumption that some supply chain innovations take place while firms adopt AM. Manufacturing firms should therefore consider the potential effects of AM on supply chain processes and management (Oettmeier & Hofmann, 2016). For AM to fully deliver its potential, it is argued that such process technology innovations require restructuring the relationships with suppliers and customers increasing collaboration (Mellor et al. 2014). As SMEs are considered to have less resources available for innovation activities (Tovstiga, 2008), the collaboration becomes important in order for SMEs to develop their competitiveness. Comprehensive studies in this area do not exist, yet, making it an important topic for further research.

**Research design and method**

This research employs an exploratory research design to study SMEs' perspective to AM-related supply chain innovations. Exploratory research design was chosen because of the emergent nature of the phenomenon. Collecting data from different companies was seen as a means to achieve the best possible overall understanding. The industry context is machine manufacturing and process industry where using subcontractors is common. Subcontractors most often are SMEs. This context is useful for the attempt to study anticipated changes in supply chains and the supply chain innovations needed to fully leverage AM.

The firms were selected based on their interest toward AM, and their early phase in AM adoption. The firms vary in their supply chain position, and four different positions in potential AM-related supply chains are covered: OEMs, subcontractors, industrial designers and AM service providers. Data were collected through 17 interviews with SME managers. Background information on the included companies and interviewees is presented in table 1.

*Table 1 – Background information on companies and interviewees*

| Type of company | Appr. nr. of employees | Nr. of interviewees |
|---|---|---|
| **Medium-sized OEMs** | 60-200 | 5 |
| **Small or medium contract manufacturers** | 15-160 | 4 |
| **Small AM service providers** | 5-20 | 2 |
| **AM machine supplier** | | 1 |
| **Engineering and industrial designers** | 1-250 | 5 |

The interview outline included questions concerning the background and position of the respondent; the company's experience and plans for implementing AM; identified challenges in implementing AM; possible industry-specific needs for AM; opportunities to add value for the business and its customers by using AM; and production and supply chain changes required by AM. This paper concentrates on the two last questions concerning opportunities to add value for the business and its customers by using AM; and production and supply chain changes required by AM.

The recorded interviews were transcribed. Four themes were marked in the interviews when first exploring the data: a) How is the market changing, when AM is a feasible alternative; b) How does the business environment change, when AM is a feasible alternative; c) Important issues in AM subcontracting, and d) Important issues for AM supply chain structure formation.

During the actual analysis, each theme's citations were inductively coded with more detail, to condense the interviewees' experiences and retain the terms that the interviewees used. These findings were structured thematically under the two main topics: AM-driven changes in the supply chains (original themes a and b), and needed supply chain innovations (original themes c and d). Changes were grouped inductively into four categories (Table 2), and supply chain innovations were grouped based on the thematic frame proposed in earlier research, into innovations in supply chain business processes, technologies and network structures (Arlbjørn et al. 2011, also Table 3). To present the results, tables of core categories in these two topics were formed and also response frequencies were calculated for illustrative purposes.

## Findings

*AM driven changes in supply chains*

Many of the respondents expressed that traditional manufacturing still dominates, and AM technology is the concern of specialized AM companies primarily. According to one interviewee, "There are so many new areas in metal printing that it certainly will not be the business of every company." (Industrial design) However, also various changes were expected in the supply chains due to AM, and we mapped them (Table 2) into four categories: Digitalization of the entire design-to-manufacturing chain, AM flexibility complementing traditional manufacturing, change in operations management, and changes in logistics and suppliers.

*Table 2 – Expected AM driven changes in supply chains (x = in how many supply chain positions the subject was mentioned).*

| AM driven change in manufacturing and supply chain | Importance | Example quotations |
|---|---|---|
| **Digitalization of the entire design-to-manufacturing chain**<br>Digitalization increases the need for trusted business partners | xxxx | "The whole supply chain must start using digital plans and the key issue is to agree the roles. It must start from designing so that manufacturing can start leveraging digitalization." (subcontractor)<br>"The trust and security is emphasized in digital services" (AM service provider) |
| **AM features complementing traditional manufacturing**<br>Changes due to "economies of one": Orders only for demand, no need for big batches to gain cost advantage from the economies of scale | xxx | "The supply chain is going to be faster, when you don't need to order big batches because of the price" (Industrial design)<br>"AM is well suited to complement a wide range of operators, large companies have their own machines in production, product development or spare parts business and certainly service providers and subcontractors will implement their models." (AM machine supplier) |
| **Change in operations management**<br>Some steps will be left out from the manufacturing process and the flexibility of batch sizes challenges traditional production management | xx | "Of course AM will cause significant changes. Manufacturing steps are left out, really much I presume. And, indeed, the whole environment of the enterprise resource planning changes." (OEM)<br>"This will change operations management, because every part can be different – it brings flexibility – but on the other had it can be quite slow compared to machining. There will be possibilities for new product development, testing and ramp up that no one has utilized, yet." (Industrial design) |
| **Change in logistics and suppliers**<br>Integration of components reduces the need for logistics and multiple suppliers | xx | "And if integration within one engine reduces the need of 855 parts to 12 parts, then it has a strong impact on supply chains." (Industrial design) |

Digitalization of the entire design-to-manufacturing chain is a change that was experienced in all types of companies. It is an ongoing change, but also an opportunity for innovations to streamline supply chains. The interviewees expressed that the change towards full digitalization increases the need for trusted business partners, to be addressed in supply chain definition and partner selection. Also such companies that rely on their traditional manufacturing are heavily relying on their partner companies, for example, in terms of research and development or post-processing.

According to the interviewees, AM as a flexible manufacturing method will complement traditional manufacturing. AM allows production based on the "economics of one", which enables firms to manufacture orders only for demand. Consequently, the need for big batches as a means to gain cost advantage from economies of scale will decrease. This opens up possibilities for entirely new operational models that have not been possible before. Interviewees suggested that the small batch orientation will also lead into changes in operations management, because some steps will be left out from the manufacturing process and the production type will change. This again creates an opportunity to develop operational activities and new innovations.

Change in logistics means that with integrated parts there is a possibility for reduced or simpler logistics. Lighter parts also may reduce costs, if logistics costs are calculated based

on weight. The number of suppliers may also be decreasing due to AM, as one interviewee predicted that the usage of casted metal parts would decrease when AM replaces them. Even though logistics may decrease in general, the interviewees mentioned that the necessity for the post-processing of components still requires logistics providers, at least currently when AM service providers do not have advanced post-processing capabilities. Therefore it would be useful to locate post-processing companies within a close proximity to the AM service providers.

*Needed supply chain innovations*

In order to leverage AM in their firms, SME managers expected that various innovation actions are required and these actions are presented in table 3. The most often expressed needs deal with new practices in product development and a partnership approach in the supply chain, expressed by over a half of the respondents. Each of the other topics were discussed by two to six respondents.

*Table 3 – Expected needs for innovations in SME supply chains to leverage AM*

| **Element of supply chain innovation** | **Description: domains where innovations are expected** | **Presence in the interviews** |
|---|---|---|
| **Innovations in supply chain business processes** | • Product development<br>• Order fulfillment<br>• Demand management<br>• Customer/supplier relationship management<br>• Service capacity | Expected in various ways in all types of firms; particularly strongly among industrial designers |
| **Innovations in supply chain technology** | • Investments into digital systems in the entire design-to-manufacturing chain<br>• Change in manufacturing methods | Expected in all types of firms; both issues particularly in OEMs and service providers |
| **Supply chain structure: Innovation with suppliers/customers** | • Partnership, cooperation<br>• Specialization<br>• Expertise centers: clusters of specialized companies in the same location<br>• New actors and job descriptions<br>• Partners initiating the AM innovation and use (subcontractors/customers/service providers) | Expected in multiple ways and fairly evenly in all types of firms |

Supply chain innovation during AM adoption depends on the strategies of certain leader firms, within SME sector or amongst large companies that are sourcing from the SME sector. However, the interview data suggests that it is not clear who should own the AM machines. Currently service providers are the only companies that had implemented industrial scale AM, but they will also need a strong and collaborative supply chain for AM to become competitive. SME managers also anticipated that new actors may be emerging in the AM-oriented supply chains. Also when the technology advances, it may open up possibilities for other companies to implement AM machines.

Based on the interviews, supply chain business process innovations deal with product development, order fulfillment, demand management, customer/supplier relationship management, and service capacity. Innovations in product development processes are expected because of the faster iteration cycles with real components instead of mock-ups or weak quality prototypes. The capacity fill rate of the building platform plays a crucial role in terms of costs. Optimizing the fill rate is, therefore, a goal for companies that have

implemented AM and it will require innovations in order fulfillment, demand management and service capacity. Service capacity means fast delivery, capacity to do multiple batch sizes, quality and reasonable pricing.

Supply chain technology innovations were expected in terms of investing in such digital systems that promote the digitalization in the entire design-to-manufacturing chain, and the change of manufacturing methods. Investments into digital systems throughout the processes was considered as a possibility to streamline the design-to-manufacturing chain effectively and enhance transparency. The change of manufacturing methods means that with AM technology, supply chain management has new tools to make manufacturing processes more flexible.

Supply chain structure innovations and more precisely innovations with suppliers and customers deal with models of cooperation, specialization and co-location of expertise, emergence of new actors and job profiles, and alternative initiators of innovations. The suitable operation model in the supply chain structure according to the interviews is cooperation which requires finding the right partnerships. AM technology is new and complex, and good cooperation between the customer and the supplier is needed to maximize R&D innovations. Some interviewees experienced that specialization would be the best operating model for cooperation whereas others went even further and responded that expertise centers should be formed for AM. Expertise centers were described as multiple specialized companies inside the same building or at least in a very close proximity, where partnership is close and several companies can work like one company. More actors and new job descriptions are expected to emerge in the supply chains in each scenario. New actors could most likely emerge in the field of total AM chain management that would optimize all steps in the value chain and handle the quality assurance. Based on one interviewee, this would be the best way of managing expertise centers.

For the question who should be the leader of AM implementation and network innovators, one interviewee in an OEM firm answered that they would like to source AM parts or services traditionally from a subcontractor with the lowest cost. Interviewees in other OEMs saw collaboration or cooperation as a better model, although they mentioned that they will expect their subcontractors to be the initiators for providing new technology capacity to them. Subcontractors on the other hand are waiting for their customers to ask them to provide AM capabilities or in the best case start to co-develop AM with them. Large companies are expected to implement AM if they have a very crucial component that is re-engineered for AM. Otherwise large companies are expected to source AM parts from their supply network.

**Discussion and conclusion**

The first research question asked: "*What types of changes do SME managers anticipate from AM in their supply chains*?" Four major changes were identified: Digitalization of the entire design-to-manufacturing chain, AM complementing traditional manufacturing, change in operations management, and changes in logistics and suppliers. These findings offer empirical support for some earlier conceptual studies (Holmström et al., 2010; Holmström and Partanen, 2014). The general finding that companies expect AM to complement traditional manufacturing rather than replace it lends support to Rylands et al. (2016) view. The most frequently expressed change concerned the digitalization of the entire design-to-manufacturing chain, which has not been discussed in previous studies sufficiently. Although digitalization is not solely an AM specific change, AM and other digital manufacturing technologies are driving industry toward a more digitalized direction. On the other hand,

leveraging the digital manufacturing technologies fully will require adopting a holistic view to the digitalized supply chain. This change may have effects far wider than just for manufacturing processes for example in customer relationships and in new product development.

The second research question inquired: "*How can SMEs leverage AM through innovations in their supply chains*?" We identified a total of twelve needed innovation expectations that were divided in three categories based on the framework of Arlbjørn et al. (2011). The findings suggest that manufacturing technology innovations such as AM cannot be seen as isolated innovations that could be leveraged merely as a technology adoption task. Instead, they need to be viewed as a systemic innovation requiring complementary innovations to realize their benefits in full scale (Chesbrough and Teece, 2002).

Implementing an AM machine and AM-driven processes is a demanding investment both financially and operationally. It requires new know-how within a company, as well as supply chain innovations that emphasize collaboration, cooperation and specialization. A collaborative approach has been emphasized in this study, as a means to benefit from AM driven changes especially in the SME context affirming Oettmeier & Hofmann (2017) predictions. Engaging the supply chain more broadly in AM-related discussions will help the different firms to justify their investment decisions, negotiate their network position and access other companies as sources of complementary capabilities.

This study was conducted using an exploratory interview-based research design. This type of research design allowed to look at the phenomenon widely, but not very deeply. All the companies were from machine and process industry, which limits the findings into this context. Furthermore the companies were from different supply chains, so conclusions within a single supply chain cannot be made. In the future, a single supply chain and its AM investment should be investigated to confirm this study's expectations and develop them further.

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