Supply chain modifications to improve additive manufacturing cost-benefit balance

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Abstract

Additive manufacturing (AM) offers unique production characteristics which among those, toollessness and production of complex geometries are potentially significant to operations efficiency. Previous research has illustrated the potential sufficiency of this technology to affect the supply chains' arrangements and enabling decentralized production configurations. While, one of the important advantages of AM enabled distributed production is the increased flexibility, which is a necessity in today's competitive and ever changing global supply chains, number of obstacles have kept this method from wide implementation. In this paper, we study the possible supply chain modifications to decrease the cost of an AM-enabled decentralized production system. In other words, we perform a cost-benefit analysis on various AM supply chain strategies in a spare parts context to realize the independent operational factors affecting the implementation cost of additive manufacturing. Moreover, we analyze the ways to adapt the supply chain management to enable full potential of AM considering the present technology.

Introduction

In today's global competitive business environment, the value of manufacturing flexibility is ever increasing. To satisfy the customers' demand and increase market share, firms try to provide more versatile range of solutions with high quality while keeping the costs under control. Manufacturing flexibility refers to the capability of an organization to produce what is required when it is required and where it is needed. An improvement in the flexibility of spare parts provision operations can significantly reduce the after sales service provision costs through the inventory and transportation reduction. Additive manufacturing (AM) enabled distributed production fulfills this.

In a previous study, Khajavi et al. (2014) investigated two extreme case of AM implementation in supply chain of spare parts. These two scenarios are fully distributed and centralized supply chain arrangements. The first scenario represents a setting which the production facilities are all located in a single place while the second one assumes that every consumption location utilizes the required AM production machines. However, there is a measurable gap between the costs for these two scenarios (Figure 1). Although distributed model provides the much needed flexibility, it is not currently economically feasible due to a number of factor (high amount of initial investment and personnel cost).

However, it is worth studying what are the other possibilities through the implementation of other supply chain strategies between these two extreme scenarios.

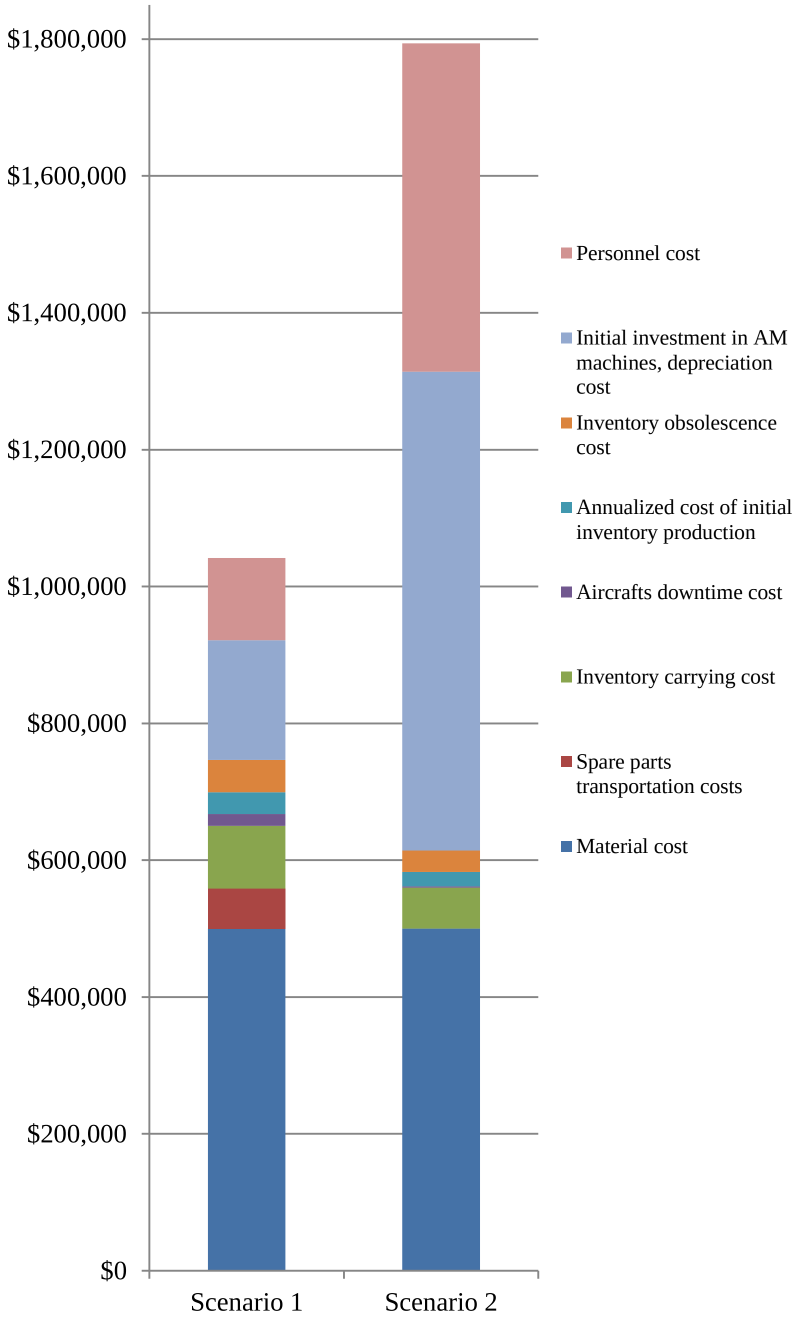

Figure 1- Total operation cost breaking for all investigated scenarios.

Spare parts management always was among the most challenging tasks in the manufacturing related products. Challenges are related to the fact that demand does not follow any predictable pattern (Boylan & Syntetos, 2008), which sparks the tenancy to hold high inventory levels or the use of more expensive transportation methods (e.g. Dell supply chain). Holding high inventories not only yields great carrying costs and capital expenses for slow-moving parts, but also significantly elevates the risk of parts obsolescence. Therefore, there is a need for increased flexibility to reduce the inventories while increasing customer service level to rapidly fulfill the demand.

Conventionally, companies invested heavily in their spare parts supply chain operations to reach high fulfillment rates and reliability (Cohen, 2006). ICT- enabled technologies like enterprise resource planning (ERP) and mathematical models such as operation research, have been used to alleviate these problems (Akkermans et al., 2003; Cheong et al., 2007). However, during the rapid development of digital manufacturing and particularly 3D printers, new solutions are emerging to aid spare parts supply chain management. Applying decentralized additive manufacturing model is one of the novel solutions in this respect. In this paper, we study the obstacles which prevent the wide implementation of this solution for the spare parts supply chain in a conceptual manner and propose a number of potential solutions.

Gap in the literature

Although researchers had explored the benefit and shortcomings of AM technologies (Hopkinson, 2006; Holmstrom et al., 2012) and also provided a cost comparison between different supply chain configurations (Khajavi et al., 2014). There is not any effort which we are aware of, that evaluates different supply chain practices to realize if distributed AM production might become more economical in a spare parts context. Therefore, in this research, we try to answer the following question;

What are the possible supply chain management policies that can reduce the cost of a decentralized AM implementation and how these policies will reduce the overall cost?

In this specific paper we aim to study only the current AM technology and not include the possible advancements which might come along in the future.

The remainder of this paper is organized as follows. We first present a short review about AM current configuration and production positioning models. Next, we review the common model in spare parts supply chain. Then SCM strategies and modifications to enable distributed AM production will be introduced and finally paper will be summarized with conclusions and directions for the future research.

Additive Manufacturing

Additive manufacturing also known as 3D printing is a manufacturing method which builds parts through the selective addition of material in the required positions, layer by layer. This method commonly utilizes three dimensional computer added design files in STL format to initiate the build process (Hopkinson et al. 2006). The benefits and shortcomings of this method in comparison to the conventional manufacturing methods can be found in the Table 1.

Table 1: Benefits and shortcomings of AM (Zäh & Hagemann 2006, Holmström et al. 2010).

Benefits	Shortcomings
- More flexible development - Easier design and construction - Integration of functions - Less assembly - No production’s tooling - Less spare parts in stock - Less complexity in business because of less parts to manage - No tools for productions need to hold in stock (only digital/CAD data) - Less time-to-market for products - Faster deployment of changes - Offer of individual products	- Available software is a limiting factor - High machine and material costs - High calibration effort - Quality of parts is in need of improvement - Rework of parts is often necessary (support structures) - Building time depends on the height of the part in the building chamber

Production Positioning

There are two extreme types of AM positioning models to choose from (Holmström et al. 2010). First, centralized model in which production facilities are concentrated in a particular location and serve the world market from that location. The other option is decentralizing production; where production facilities distribute in various regional or national locations close to the major markets (Hill & Jain, 2007). Distributed production may lead to various advantages. These potential benefits include achieving higher flexibility, instant receiving of information from local market, increased chance to improve decision making accuracy, optimizing the supply-demand management and gaining higher supply chain reliability (Parry, 1997). Furthermore, it provides lower capital investment in each facility and lower shipping costs (Hawken et al. 2010).

Nonetheless, conventional model of spare parts supply chain acts more like a centralized system.

Figure 2, depicts a schematic view of this models in a simple perspective. As we can see, huge amount of inventory and products buffer have been kept to respond to the customers' demand.

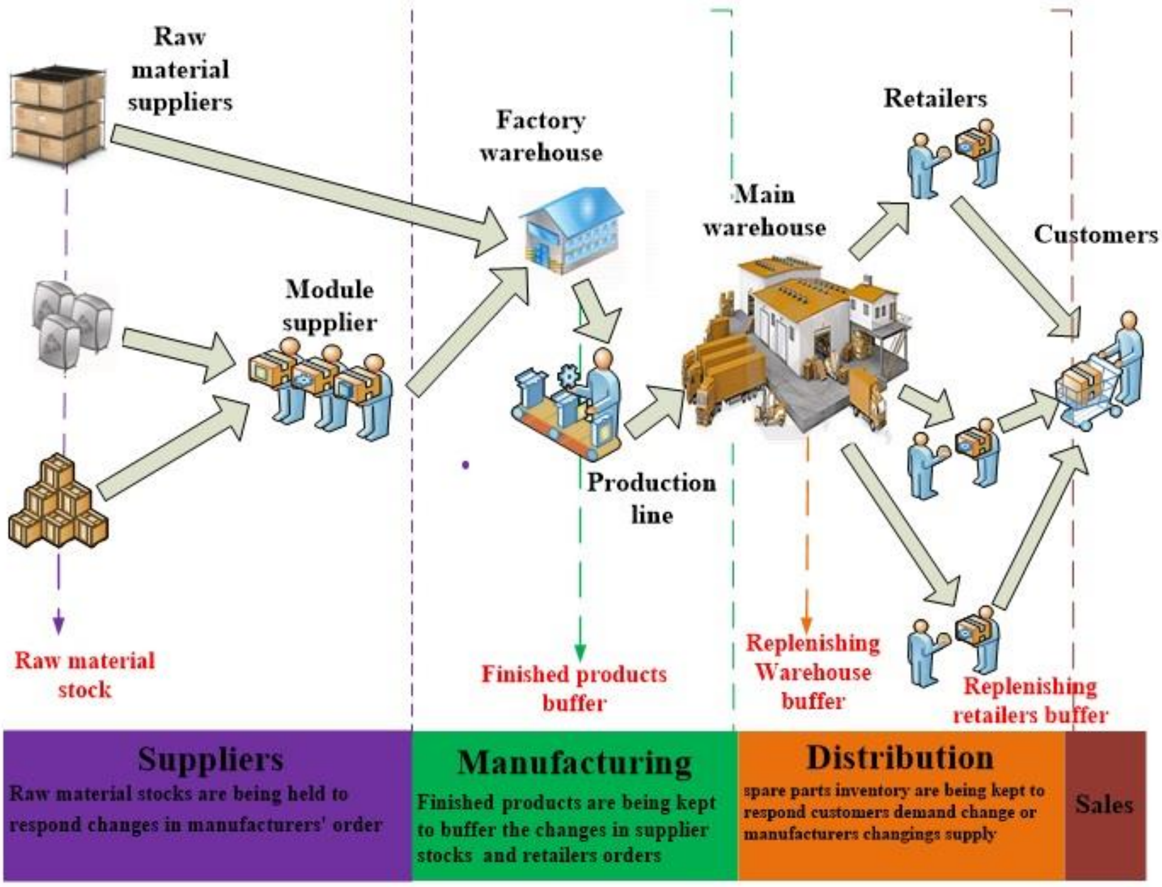

Figure 2- Conventional model of spare parts supply chain.

We recognized three supply chain strategies which can improve the cost- benefit balance of an AM implementation and enable its benefits in the current technology setting.

Supply Chain Strategies

Before explaining the supply chain modification strategies we should first explain the supply chain in general. Various description of supply chain exists in the literature; Mentzer et al. (2001) in their paper for instance describe it as “a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finance and /or information from a source to a customer”. Lambert et al. (1998), describe the supply chain in another way as “The alignment of firms that bring products or services to market”. Another description by Chopra & Meindl (2001), emphasizes on the various components of supply chains; “a supply chain consists of all stages involved, directly or indirectly, in fulfilling a customer request. The supply chain not only includes the manufacturer and suppliers, but also transporters, warehouses, retailers, and customers themselves”. The latter description is the one being utilized to study the supply chain complexities in this research.

Production hubs

Figure 3- Hub production for the Khajavi et al. (2014) case study (Modified reprint for Khajavi et al., 2014 article)

Supply hub defines as a location sited very near a manufacturer’s facility where all or some of its supplies are stocked with the agreement that the materials will be paid for only when consumed (Zuckerman, 2000).

The use of supply hub is very suitable for some industries that encounter turbulent and uncertain market demand or very short product life cycles. It is also imperative for the industries which face uncertain supply lead times such as consumer electronics products (Shah & Goh 2010). Generally, supply hubs have been used further after the ubiquitous implementation of Vendor Managed Inventory (VMI). Many electronic and computer manufacturers adopted supply hubs to store raw materials and components offered by their suppliers. It aided them to tackle the shrinking of production life cycle, thereby achieving cost reduction and improved responsiveness (Qiu, X, et al. 2010).

Supply hub strategies provide many advantages. Dai et al. (2000) find that the Supply-Hub is an innovative strategy to reduce cost and improve responsiveness. Furthermore, supply hubs are streamlined approach for managing inventory by suppliers for the customers.

Supply hubs also make an integrated supplier's network by providing a unified system between first and lowest tier sub-suppliers (Hvolby & Trienekens, 2002).

Nevertheless, there are some arguments against using of supply hubs. Dai et al. (2000) list these downsides as:

1. Supply hubs enforce suppliers to share their information with other suppliers and the hub manager.

2. Supply hubs need to set up information system for inventory visibility and it is costly. This cost is not easy to afford by small suppliers.

3. Creation of another intermediation point in the supply chain.

Moreover, the hub production concept which can be enabled by the AM technology is closely related to the supply hub meaning; the only difference is that production happens in the locations which are near the high consumption locations (high consumer density) instead of positioning the warehouses in those locations. For instance, the hub production for Khajavi et al. (2014) research is as illustrated in Figure 3 which has two AM production facilities to supply the east and west coast navy bases independent of each other. This strategy while decreases the amount of initial investment in AM machinery also reduces the number of skilled workforce which is required compared to the fully distributed scenario. However, this scenario will require higher amount of inventory as it should serve more locations at any given time. Moreover, the transportation times will add to the demand fulfillment process time span and might increase the down time cost to some extent. From the above mentioned negative side effects of a supply hub, only the need for an information network applies to the production hub strategy which we explore here.

Supply hubs may also reduce personnel cost dramatically. Sources of personnel cost in AM production consist of skill and labor required for the pre and post production process. For the post production side, costs are associated with the loading, unloading, support removal and cleaning of parts. Beside this, the production process is automated and labor is not necessary. (Lindemann et al., 2012).

On the other hand, pre-production labor cost, which includes data preparation, is relatively a tangible amount. In the preparation process, skilled and experienced personnel are needed. It includes the skills and knowledge in making and modifying the three-dimensional model and knowledge to place the parts in the building chamber (Lindemann et al., 2012).

We propose to centralize pre-production activities to save cost and facilitate communication work. For post-production personnel, we propose a distributed scheme in the hubs near the customer markets. This might yields faster work process and improving responsiveness to the customers' demand.

Furthermore, in the ever changing current business, it is not enough for the services supply chain to only optimize the matches between supply and demand. Firms must respond frequently to the market changes and manage their services network in a dynamic fashion (Cohen et al. 2006). As a result, using supply hubs in distributed AM model can create a dynamic approach and provide better connection between company's service network and customers.

In addition, supply hub strategy enables ordering bulk raw material. It is not possible in the fully distributed AM model. Ordering in bulk volumes decreases total material carrying costs as well as material purchasing price.

Postponement strategy

Postponement is another supply chain strategy. This strategy implies to reduce the risk, uncertainty and its related costs of different goods in the market by delaying the production until the demand is there. Alderson (1950) and Bucklin (1965) introduce this concept and questioned where, when and who should hold inventory in order to reduce cost and risk. Postponement is a multidisciplinary modification that impresses the entire supply chain. Van Hoek (2001) refers postponement as a dramatic change in organizational concept whereby some of the activities in the supply chain are not performed until customer orders are received. The rationale in postponement is the inherit risk and uncertainty costs associated with the differentiation of goods (i.e. form, place and time) that occurs during manufacturing and logistics operations. Pagh & Cooper (1998) extend this concept and distinguished between manufacturing postponement, logistics postponement and full postponement.

Supply chain strategy deals with some determinants to develop the postponement applications. These determinants include product, market demand, manufacturing and logistics. Pagh & Cooper (1998) define the postponement strategy as the following customization part of the "Just-in-Time"(JIT) production methods. Therefore, manufacturing postponement benefits in reducing the finished products inventory (Brown et al., 2000) and providing the chance to forecast the changes earlier (Christopher, 2000).

Hsuan et al. (2004) conclude that postponed manufacturing systems allow companies to separate their customized products from the manufacturing of standard components. They indicated that acquired flexibility through the postponement can create a network of organizations, modularized in standardized component manufacturing and customized final assembly. This transparent operating system allows selecting the best suppliers to the particular products requirements in every module and managing the supply work easier (Hsuan et al. 2004).

Nonetheless, production postponement includes some downsides and risks. For example, this strategy requires precise and quick information about customers' needs as well as rapid response. According to Yang & Burns (2010), these impending risks decrease use of postponement strategy. Hence, postponement applications mainly involve in downstream activities in the supply chain.

In the spare parts supply chain, AM can be the enabler of production postponement. Postponement strategy will improve the suppliers' related costs (both for the module and raw material suppliers). Consequently, it will decrease "inventory obsolescence" and "inventory carrying cost" while might negatively affect the equipment downtime cost because the production after the demand is received will need more time when it compared to shipping form the inventory.

Online Customization and Distribution Platform

Information technology (IT) has dramatically redefined the relation between suppliers and customers. Internet makes an online market place in which suppliers, manufacturers, logistics service providers and customers can meet and able to search, order, sell products and services or use the online market to communicate among the supply chain members. The Internet-based SCM is one of the systems to follow, monitor and control the supply chain activities. (Süleyman, & Gürdal, 2010).

Moreover, studies has recognized many benefits for internet-based supply chains such as faster transaction, decreased cost, improved business efficiency, promoted information flows, wider geographical coverage, increased temporal reach, increased chance to differentiate products from competitors, ability to shorten the supply chain and acquire flexibility in the supply chain. (Lancioni et al. 2000, Garcia-Dastuque and Lambert. 2003, Rahman, 2003; 2004, Lo et al. 2008)

However, one of the major obstacles in front of this strategy is that internet-based online supply chain needs information integration throughout the entire supply chain. Furthermore, traditional manufacturers are usually unwilling to adopt total web computing business models due to some reasons such as intellectual property (IP) and knowledge sharing issues (Ghiassi & Spera, 2003). Therefore, sophisticated enterprise resource planning (ERP) solutions have been developed to control the supply chains within and beyond the organizational scope to resolve the integration issues (Majid & Mohamed, 2000). These solutions make it possible to adjust the ordering selection into the 'last minute selection' which leads to improving the flexibility and usability of manufacturing (Zhang et al., 2014).

Nonetheless, ERP systems have been faced with some restrictions in supply chain management. These limitations can be classified in four major groups: (1) lack of extended enterprise functionality; (2) lack of flexibility in adapting to changing supply chain needs; (3) lack of advanced decision support capabilities; (4) lack of open, modular system architecture (Akkermans et al., 2003). Cloud-based solutions introduced and implemented to cover the limitations of ERP-solutions. Even though, could-based supply chain solutions still consist of major shortcomings. For instance, companies may lose the full control over their valuable data in the supply chain and have to rely completely on the cloud solution provider (Mangiuc, 2011). Furthermore, there are additional issues might happen related to vendor lock-in, compliance challenges, and cloud provider acquisition (Khajeh-Hosseini, 2010).

Considering these aspects, we suggest an online customization platform in the spare parts supply chain. This platform is a way to create a feedback loop. According to Hugos (2011), companies can use feedback loops to collect useful data through the interactions within electronics purchase orders. Their performance will be marked by other players in the supply chain, so they can adjust their negative feedbacks very fast. Similarly any change in the supply chain will be reported within the online platform and will be visible for every player in the supply chain. It is essentially useful in the spare parts supply chain as one of the biggest challenges in the spare parts management is volatility and unpredictability of the market.

In the new era of 3D printing, products become more customized based on the needs of every single customer (Lipson & Kurman, 2013). Combination of internet-based services and AM paves the way for a remarkable change in the spare parts supply chain because AM makes it possible to fulfill the requirements of an online customized platform.

In the centralized AM model, several middle men exist between the customers and supplier. It leads to the few chance of making a customizable offer. Manufactures are able to omit these players and connect directly to customers and suppliers taking the advantage of distributed AM enabled flexibility.

In this study, we use the suggested internet-based online platform for "Order Processing" .Thus, we seek out an online platform beside the traditional break and mortar ordering model. This customized online ordering platform can save money in the inventory obsolescence cost, initial inventory production cost and probably reduce the equipment downtime cost if the parts on the equipment can become equipped with the sensors and report on their conditions before the actual breakdown takes place.

Conclusion

This study is a direct response to Khajavi et al. (2014) call for further research. We analyzed the benefit of distributed AM production arrangement compared to centralized configuration in the spare parts supply chain. As Khajavi et al. (2014) highlighted, distributed enabled AM of spare parts yielded major benefits such as reduced capacity utilization, lower down time cost, more flexibility in production, higher responsiveness to the supply chain disruptions, less necessity for inventory management and logistic information, higher chance to gain customer satisfaction and more capability to manufacture customized products. By exploring the possible supply chain modification strategies, we built a case to enable the after-sales supply chains take advantage of mentioned benefits through the AM technology.

While in the prior research, Khajavi et al. (2014) only studied two extreme scenarios (centralized and distributed), this paper proposed an intermediary model. To begin with, we categorized cost break down in distributed AM. Then, we depicted a schematic model in the generic spare parts supply chain and identified the major shortcomings. Three supply chain strategies discussed in this paper which are as follows;

- Hub manufacturing configuration,
- Production postponement, and
- Internet based customization and distribution.

Finally, we conceptually discoursed how to apply each strategy to mitigate the obstacles of distributed AM implementation and reduce the relative operation cost in the spare parts supply chain.

This paper entails some limitations. Due to the lack of relevant data, we only presented in the ideation level and did not provide any empirical result. Further research will apply this study in the real-world cases and compare the quantified results. Furthermore, for the sake of simplicity, we kept the technological development in the AM machines as a fixed variable and assumed the main characteristics of this technology will not change rapidly. However, the progress in the technology dimension of AM may affect some aspects of current models if they materialize.

References

Akkermans H.A., et al., The impact of ERP on supply chain management: exploratory findings from a European Delphi study/European, Journal of Operational Research 146 (2003) 284–301

Alderson, W., 1950, Marketing efficiency and the principle of postponement. Cost and Profit Outlook, 3, 15–18.

Barutçu, Süleyman, and Sahavet Gürdal. "INTERNET-BASED SUPPLY CHAIN MANAGEMENT: A PILOT SURVEY FOR DETERMINING THE CHALLENGES IN THE INTERNET-BASED TEXTILE SUPPLY CHAIN•." PAU J Soc Sci Ins} 2010: 177-187.

Boylan, J. E., & Syntetos, A. A. (2008). Forecasting for inventory management of service parts. In K. A. H. Kobbacy & D. N. P. Murthy (Eds.), Complex system maintenance handbook (pp. 479–506). New York: Springer Verlag.

Brown, Alexander O., Hau L. Lee, and Raja Petrakian. "Xilinx improves its semiconductor supply chain using product and process postponement." Interfaces 30.4 (2000): 65-80.

Bucklin, L. P., 1965, Postponement, speculation and the structure of distribution channels.
Journal of Marketing Research, 2, 26–31.

Garcia-Dastugue, S. J., and Lambert, D. M. (2003) “Internet-enabled coordination in the supply chain”, Industrial Marketing Management, Vol.32 (3) 251- 263

Ghiassi, M., and C. Spera. "Defining the internet-based supply chain system for mass customized markets." Computers & Industrial Engineering 45.1 (2003): 17-41.

Christopher, M. (1992), Logistics and supply chain management, Pitmann publishing, London, UK

Cohen, M., Agrawal, N., and Agrawal, V. (2006), “Achieving Breakthrough Service Delivery through Dynamic Asset Deployment Strategies”, Interfaces, Vol. 36, No. 3, pp. 259-271, May-June 2006

Dai, Jim, et al. On the strategy of supply hubs for cost reduction and responsiveness. Logistics Institute-Asia Pacific, National University of Singapore, 2000.

Majed A., Z. Mohamed, Supply-chain re-engineering using enterprise resource planning (ERP) systems: an analysis of a SAP R/3 implementation case, International Journal of Physical Distribution & Logistics Management 30 (3/4) (2000) 296–313.

Mangiuc D.M., Enterprise 2.0 – is the market ready? Journal of Accounting and Management Information Systems 10 (4) (2011) 516–534

Hill, Charles WL, and Arun Kumar Jain. International business: Competing in the global marketplace. Vol. 6. New York, NY: McGraw-Hill/Irwin, 2007.

Holmström, Jan, et al. "Rapid manufacturing in the spare parts supply chain: alternative approaches to capacity deployment." Journal of Manufacturing Technology Management 21.6 (2010): 687-697.

Hopkinson, Neil, Richard Hague, and Philip Dickens, eds. Rapid manufacturing: an industrial revolution for the digital age. John Wiley & Sons, 2006.

Hsuan Mikkola, Juliana, and Tage Skjøtt-Larsen. "Supply-chain integration: implications for mass customization, modularization and postponement strategies." Production Planning & Control 15.4 (2004): 352-361.

Hvolby, Hans-Henrik, and Jacques Trienekens. "Supply chain planning opportunities for small and medium sized companies." Computers in Industry 49.1 (2002): 3-8.

Hugos, Michael H. Essentials of supply chain management. Vol. 62. John Wiley & Sons, 2011.

Khajavi, Siavash H., Jouni Partanen, and Jan Holmström. "Additive manufacturing in the spare parts supply chain." Computers in Industry 65.1 (2014): 50-63.

Khajeh-Hosseini A., I. Sommerville, I. Sriram, Research challenges for enterprise cloud computing, in: 1st ACM Symposium on Cloud Computing, SOCC 2010, 2010.

Lancioni, R.A., Smith, M.F., and Oliva, T.A. (2000) “The Role of the Internet in Supply Chain Management”, Industrial Marketing Management, Vol. 29 (1), 45-56

Lindemann, Christian, et al. "Analyzing product lifecycle costs for a better understanding of cost drivers in additive manufacturing." 23rd Annual International Solid Freeform Fabrication Symposium–An Addictive Manufacturing Conference, Austin/TX/USA, 6th–8th August. 2012.

Lipson, Hod, and Melba Kurman. Fabricated: The new world of 3D printing. John Wiley & Sons, page 277, 2013.

Lo, W.S., Hong, T.P. and Jeng, R. (2008) “A framework of E-SCM multi-agent systems in the fashion industry” International Journal of Production Economics, Article in press.

Pagh, J. D. and Cooper, M. C., 1998, Supply chain postponement and speculation strategies: how to choose the right strategy. Journal of Business Logistics, 19, 13–33.

Hawken P., Lovins A.B., Lovins L.H., Natural Capitalism: the Next Industrial Revolution, Earthscan Publications, London, UK, 2010.

Qiu, X., George Q. Huang, and T. Qu. "Supply hubs in industrial parks (SHIP): Research perspectives." Computers and Industrial Engineering (CIE), 2010 40th International Conference on. IEEE, 2010.

Rahman, Z. (2003) “Internet-based supply chain management: using the Internet to revolutionize your business”, International Journal of Information Management, Vol. 23, 493-505

Rahman, Z. (2004) “Use of Internet in supply chain management: a study of Indian companies”,

Parry T.R., Achieving balance in decentralization: a case study of education decentralization in Chile, World Development 25 (2) (1997) 211–225.

Shah, Janat, and Mark Goh. "Setting operating policies for supply hubs." International Journal of Production Economics 100.2 (2006): 239-252.

Van Hoek, R. I., 2001, the rediscovery of postponement: a literature review and directions for future research.Journal of Operations Management, 19, 161–184.

Yang, Biao, and Neil Burns. "Implications of postponement for the supply chain." International Journal of Production Research 41.9 (2003): 2075-2090.

Zäh, Michael, and Florian Hagemann. "WirtschaftlicheFertigungmit Rapid-Technologien." Anwender-LeitfadenzurAuswahlgeeigneterVerfahren. München: Hanser (2006).

Zhang, Lin, et al. "Cloud manufacturing: a new manufacturing paradigm." Enterprise Information Systems 8.2 (2014): 167-187.

Zuckerman, A., 2000. Compaq switches to Pre-position inventory model. World Trade, 72–74.