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TRANSFORMATION OF LOGISTICS AND SUPPLY CHAIN MANAGEMENT IN CONTEXT OF DELOPING ADDITIVE MANUFACTURING

Master's Thesis by the 2nd year student

Concentration — International Logistics

And Supply Chain Management

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ЗАЯВЛЕНИЕ О САМОСТОЯТЕЛЬНОМ ХАРАКТЕРЕ ВЫПОЛНЕНИЯ ВЫПУСКНОЙ КВАЛИФИКАЦИОННОЙ РАБОТЫ

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Описание цели, задач и основных результатов	Данная магистерская диссертация посвящена изучению технологии 3D печати в контексте влияния на логистику и управление цепями поставок (УЦП). Экспертные мнения относительно будущего технологии 3D печати высказываются в основном в виде предположений и прогнозов. Тем не менее, множество компаний внедряют 3D печать на производстве уже на протяжении нескольких лет, что дает возможность оценить реальный эффект 3D печати на логистику и УЦП и понять насколько верны многочисленные предположения о радикальном характере изменений, вызванных применением технологии. Целью исследования являлось изучение эффектов от внедрения 3D печати и их критичности для изменения глобальных практик в сфере логистики и УЦП. Стратегия кейс-стади была выбрана в качестве методологической основы. Эмпирическое исследование основывается на изучении кейсов шести компаний из различных отраслей, внедряющих 3D печать. В результате исследования было выявлено, что большинство компаний использует 3D печать для получения краткосрочных операционных выгод. Только две компании продемонстрировали стратегический подход к применению 3D печати. Также было выявлено, что через 7-10 лет цена материалов для 3D печати значительно упадет, ассортимент расширится, а также будут улучшены качественные характеристики принтеров. Совокупность этих факторов приведет к массовому внедрению технологии и слиянию функций R&D, ИТ и УЦП внутри организации.
Ключевые слова	3D печать, аддитивные технологии, логистика, управление цепями поставок, дигитализация логистики

ABSTRACT

Master Student's Name	Elizaveta Kuznetsova
Master Thesis Title	Transformation of logistics and supply chain management in context of developing additive manufacturing
Faculty	Graduate School of Management
Main field of study	38.04.02 Management
Year	2016
Academic Advisor's Name	Associate Professor, Konstantin V. Krotov
Description of the goal, tasks and main results	Current thesis is devoted to examining 3D printing (3DP) technology in context of logistics and supply chain management (SCM). Experts' opinions regarding the future of 3DP technology are expressed mostly in projections and forecasts. Nevertheless, many companies have already been applying 3DP for a few years what gives opportunity to assess

	real effect of 3DP on logistics and SCM practices. In its turn, it will help to understand to what extent numerous predictions of radical impact of 3DP on SCM are true. Thus the goal of the study was to investigate the effect of 3D printing technologies and its criticality for changing global logistics and supply chain management practices. Multiple case study was chosen as a main research strategy. Empirical evidence includes cases of six companies from various industries implementing 3DP in their production processes. It was revealed that majority of companies apply 3DP for gaining short-term operational advantages. Only two firms demonstrated strategic approach towards 3DP implementation. It was also revealed that in 7-10 years the price for raw materials for printing will drop significantly, the assortment will widen and some quality characteristics of 3D printers will be improved. The complex of these factors will lead to mass implementation of 3DP in companies and merge of R&D, IT and SCM functions within organization.
Keywords	3D printing, additive manufacturing, logistics, supply chain management, digitalization of logistics

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Introduction

Today the industry of logistics and supply chain management (further referred to as SCM) is under the big impact of latest technological advancements. The most recent industrial reports on logistics and SCM with one voice talk about key trends which will shape the future of the industry. Top-trends and technologies driving logistics innovation include among others unmanned aerial vehicles, big data, augmented reality, robotics and automation, blockchain. However there is a technology marked in DHL Logistics Trend Report as the one with highest strategic priority (2014) and called by Wohlers Industrial Report as "the most exciting manufacturing revolution in living memory" (2015). It is additive manufacturing technology also known as 3D printing. As DHL report states, the impact of 3D printing on logistics industry was and continued to be a hotly debated topic.

3-dimensional printing (further referred to as 3DP) is a component of additive manufacturing field. This technology was introduced 3 decades ago but its business application has started quite recently. 3D printing technologies caused dramatic shifts in value chains. It challenges some players to struggle to save their competitive positions but at the same time gives enormous opportunities to more open-minded firms.

Some experts argue that 3D printing is a source of next industrial revolution (Jia et al.,2015) because technology is expected to bring changes to various areas. But the sphere where the biggest potential value of 3DP lies is logistics and supply chain management. 3DP is expected to solve biggest SCM problems: make supply chain more responsive and cost-efficient by manufacturing closer to the point of use, drastically reduce lead times and inventory levels, to decrease a complexity of supply chain. However the curious point is that by bringing abovementioned improvements, 3DP actually places in question the existence of logistics and SCM as a discipline.

Experts generally agree that 3DP could have devastating outcomes for logistics and supply chain industry (Elms and Low, 2013; World Economic Forum, 2013). However all the listed effects are hypothetical and there is a lack of researches demonstrating to what extent SCM practices has already changed due to 3DP adoption. We argue that time lag for effect from every new technology to become visible is reduced significantly and it is already possible to make some first conclusions. That is why this thesis fairly states the issue of 3DP real impact on supply chain management. Here, the term "impact" specifically refers to changes in companies' operations, logistics and supply chain management performance. This paper investigates whether this impact is truly dramatic and does it have a potential to change global

supply chain management practices. It also includes the forecast on the time horizon of 3DP to bring critical changes based on real cases of companies applying 3DP and expert opinions.

Moreover, the topic is especially relevant nowadays because the most recent researches assert that investments decisions regarding additive manufacturing are classified as highly strategic (C. Weller et al., 2015). There are no doubts that 3D printing is one of the most important cutting-edge technologies in last decades. Companies which strive to be innovative by default feel the necessity to try new technology and to demonstrate it to wide publicity. So it is fair to ask whether high strategic value of decisions regarding 3DP is caused by their real criticality or just by necessity to maintain status of innovativeness. This thesis reveals whether there is more buzz around 3DP or it truly brings dramatic changes into firms' operational strategies and supply chain management practices.

Therefore, the goal of this paper is to investigate the effect of 3D printing technologies and its criticality for changing global logistics and supply chain management practices. Within the stated goal the following objectives are set:

1. To review contemporary supply chain management concepts and key trends in developing 3D printing technologies
2. To analyze the state of the market of 3D printing
3. To reveal practical insights on the issue by conducting expert interviews and survey
4. To determine the directions and extent to which applying 3DP affects current supply chain management practices and
5. To develop a set of managerial implications relevant due to shift in SCM practices caused by 3DP

The first chapter of the thesis is devoted to accomplishing the first and second objectives. Scientific journals will be examined for the presence of research papers investigating the topic of supply chain management and its contemporary concepts. The second part of the first chapter is devoted to 3D printers and 3DP services market characteristics and it is installed in order to reveal key trends in developing 3DP technologies and actual state of the market. Performed review reveals the research gap which is in the lack of retrospective papers analyzing the performance of firms already applying 3D printing in their activity. Research questions are formulated in order to bridge this gap.

RQ1: What is the direction of the changes brought by 3DP to SCM practices?

RQ2: Why these changes may become critical for shifting global logistics and SCM practices?

RQ3: What are the most probable scenarios of development 3DP in context of SCM practices for the nearest 5-10 years?

The second chapter describing methodology of the research contributes to attaining the third objective. Since the phenomena examined in this research is innovative and evidence from real companies is very relevant, multiple case study is chosen as a research strategy. To accomplish stated objectives, expert interviews with representatives of companies applying 3DP were held. Managers of a few small- and medium-sized Russian companies were asked about the reasons, motives and effects of implementing 3DP in their activity. In the third chapter results of empirical investigation are presented thus accomplishing the fourth goal. Moreover, post-hoc analysis is performed: insights gained from case study are further tested by means of survey.

Collected results are carefully analyzed in the Discussion and Findings part. Summarizing the results of previous investigation contributes to formulating final part with recommendations for the companies which consider the opportunity of employing 3DP in their operational activity.

Chapter 1. Review of the State of the Art

Since the topic investigated in this thesis is exploratory it is reasonable to gather as much relevant data as possible. Thus literature review is not directly narrowed down to analyzing the issue stated in the topic. In order to understand the phenomena, namely, potential ability of 3DP to change global logistics and supply chain management (SCM) practices, preliminary research should be performed. Analyzing latest papers on both contemporary SCM concepts and key trends in 3DP is necessary for attaining the goal of literature review – constructing comprehensive picture of how they relate to each other. That is why literature review is organized by idea. Firstly, relevant SCM practices which potentially may be affected by 3DP are presented. Secondly, key aspects of developing 3D printing technologies with emphasis on benefits, business application and limitations is presented. Then bridge between two fields is illustrated. Eventually research question is formulated based on defining the research gap after literature review is performed.

1.1. Contemporary supply chain management concepts

Supply chain management as a discipline started to gain increasing attention relatively recently. The pace of changes, growing uncertainty and complexity of business connections play critical role in this issue. Companies realize the necessity to form conscious attitude towards supply chain and logistics. In order to stay competitive they need to build viable strategies and to cooperate with other parties in supply chain.

Supply chain management concepts hasn't changed a lot since last decades. For the purposes of this thesis it is relevant to underline the definition of supply chain management, a few contemporary concepts, companies' attitudes towards supply chain management practices and its intersection with other managerial fields.

The term "supply chain management" (further referred as *SCM*) became widely used only in 1990th. Appearance of supply chain management was an attempt to give a strategic meaning to the flow of products and information between firms. Before "logistics" and "operational strategy" terms were used instead. Various definitions of supply chain management exist. They may be split into two groups: definitions emphasizing more general nature of supply chain and definitions encompassing its detailed aspects. The following definitions refer to the first group and basically they look at SCM as at management philosophy:

- SCM is the alignment of firms that brings products or services to the market (Lambert, 2010)

- SCM is an integrative philosophy to manage a total flow of a distribution channel from the supplier to the ultimate user (Cooper and Ellram, 1993)

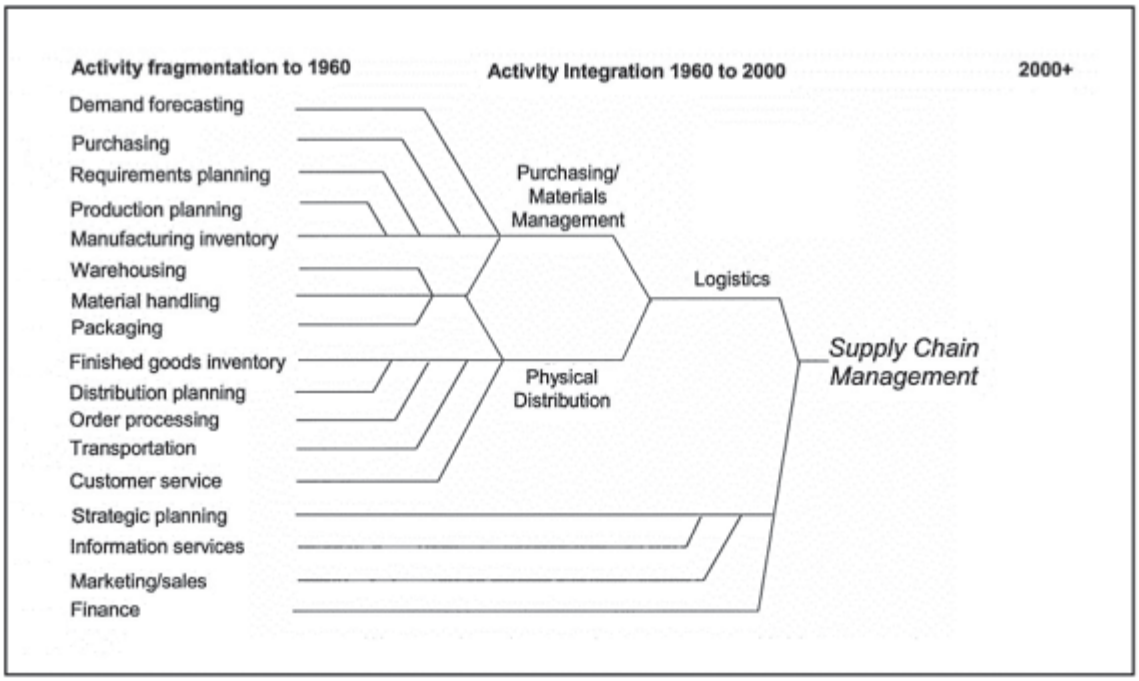
The second group of definitions looks at SCM as at implementation of management philosophy or a set of management processes:

- SCM is a systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole (Mentzer et al,. 2010)

- SCM is the management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain as a whole (Christopher, 1999)

As we observe from various definitions of supply chain management, this term is truly comprehensive and encompasses several managerial areas. Namely, SCM draws heavily from the areas operations management, procurement, logistics and information technology and strives for an integrated approach (figure 1.1). Despite researchers' attempts to establish contours of SCM as a managerial discipline (Mouritsen et al., 2003), it still encompasses various aspects of companies' activities. For the purposes of this thesis it is especially important to understand interconnections between the areas encompassing SCM. For instance during the last years various technological advancements are used heavily to enhance firms' supply chain management process. Before digital innovations mere mostly used to improve operational side of supply chain management. However the emergence of 3D printing is actually able to elevate shifts in SCM caused by digital trends to a strategic level not only tactic as it was before. 3DP has a potential to change traditional business model for logistics function and, in case of ideal scenario, switch physical flow of products towards digital.

Figure 1.1 Evolution of Supply Chain Management



Source: Ballou R. H., 2006

The definition and understanding of SCM hasn't changed from 1990[s] although its significance for companies has raised sharply. There are key factors which contributed to increased significance of supply chain management. Enhanced interdependencies between players in supply chain, current trends in allocating production facilities, worldwide economic and political situation are among the most important factors. All of them play important role in making supply chain management and other fields (e.g. politics, economics, technology, marketing) highly interrelated. It is especially important to investigate this issue because this thesis also focuses on studying interrelations, particularly between supply chain management and technology. These overlaps define today the directions of strategic development of supply chain management. A few important contemporary concepts of SCM which may be interconnected with 3DP are presented below.

Globalization has led to increased complexity of supply chains (Prater, 2013). Companies are forced to deal with multiple suppliers, clients and different intermediaries often remotely due to huge geographic distances between them. This automatically leads to extensions in supply chain. In this sense in order to manage extended supply chain successfully all its components should be carefully coordinated. These components encompass major drivers of supply chain performance – inventory, transportation, information and facilities (Bhatnagar et al., 2009). 3DP technology has a potential to impact each of these drivers. Ability to be flexible in responding to customers' needs leads to significant decrease in necessary inventory level to be kept. Decreased amount of inventories and spare parts automatically makes some facilities redundant. The role of

information changes radically – the value no more lies in ability to manufacture product but in possessing the digital model of the product which may be easily printed. At the same time, possessing this model allows to produce it in the point of use thus avoiding unnecessary transportation flows. So the implementation of 3DP may simultaneously affect the drivers encompassing SCM performance – inventory , transportation, information and facilities.

The necessity to elaborate strategies for managing each of these drivers pushed companies to think about Porter's value chain concept as relevant for this issue. Companies and industry experts started to recognize that improved management of supply chains may become a source of competitive advantage (Sherer, 2005). Since gaining competitive advantage is tightly connected with knowing and fulfilling customers' needs, companies started to focus on those aspects of SC which add the majority of value for customers. Before it was believed that value comes mostly from improvements in internal operations. However in mid 1990s the hypothesis stating that inter-organizational relations are more meaningful for improving value for customers was introduced (Sherer, 2005). Thus emphasis in managing supply chains has shifted from linear fulfillment of functions to communication and integration between different parties of supply chain. Collaborative efforts between extended number of participants in supply chain are encouraged in order to add value to supply chain activities (Poon, Lau, 2000; Balan, 2006). However the concepts of value chain and integration in SC may be challenged by introduction of 3DP technologies. Companies applying 3DP in their production processes literally reduce the complexity of supply chains by making some players redundant. Thus in frames of this thesis modern concepts of SCM will be challenged by checking their consistency with 3DP – phenomena investigated in this paper.

Another important concept developed in last years is supply chain sustainability. The management of 'sustainable' issues in supply chain is attracting much attention from the academia and corporate world. Sustainability has turn out to be a major concern for organizations to integrate ecological and societal issues in their business strategy (Luthra, 2016; Morana, 2013). In today's world it is not enough for companies to have efficient supply chains. Sustainability issues must be considered by companies in order to stay competitive (Beske, 2012; Amin and Zhang, 2014; Govindan et al., 2011; Land et al., 2015). Efforts to make SC more environmentally friendly have gained priority due to increasing threats arising from global warming and climate change (Shukla et al., 2009). Implying instruments of sustainable supply chain management leads not only to reduced environmental impact but also to increased value for customers due to cut in business wastes (Govindan et al., 2014).

Researchers discuss particularly SCM practices which affect sustainability. As soon as the term SCM includes logistics and transportation, it is often accused as being environmentally

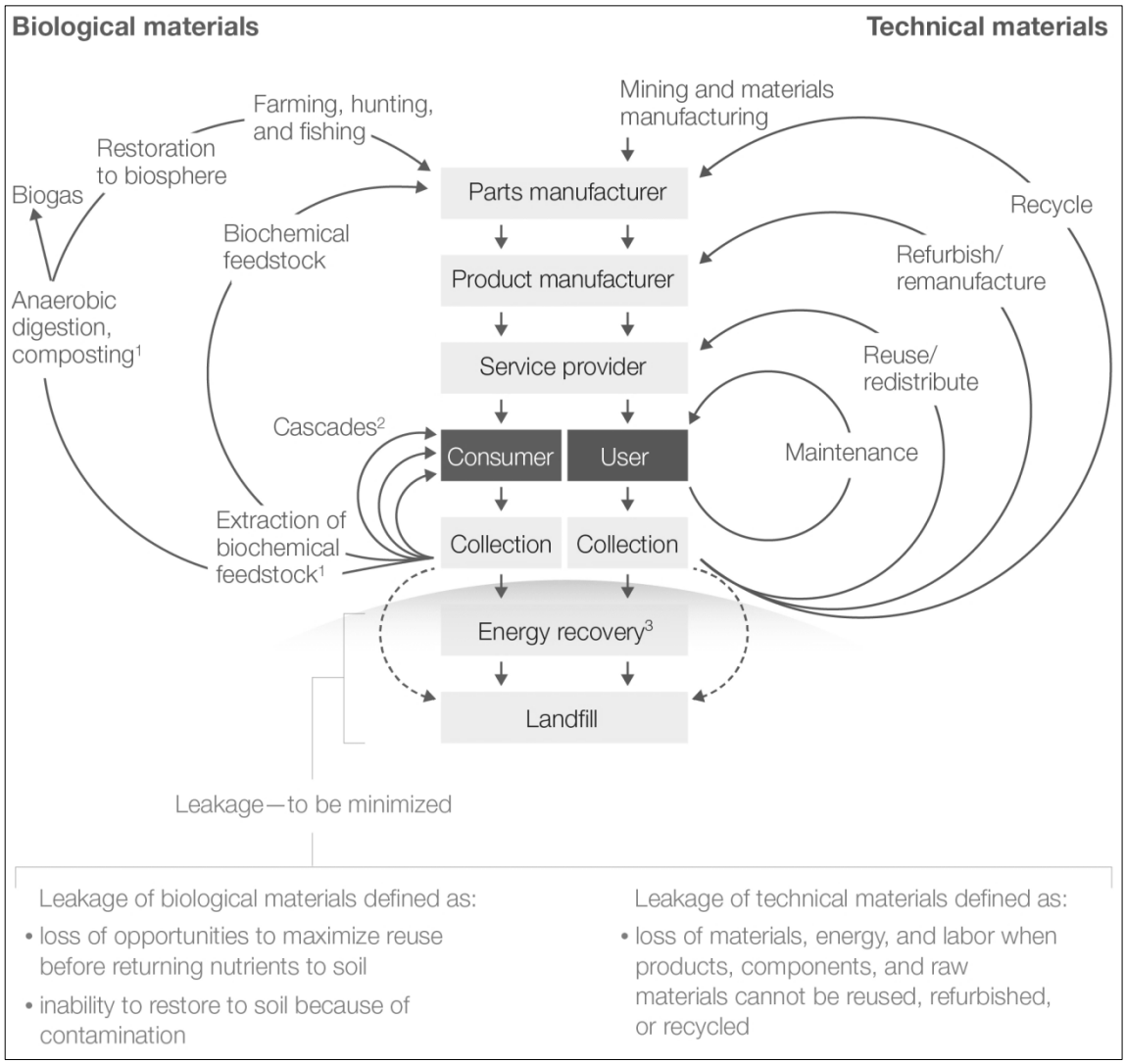
irresponsible. Moreover, some of the popular production concepts also contributes to considering SCM as eco-unfriendly. A lot of discussions are led around lean production concept. It includes different practices some of which lead to environmentally friendly results and some imply totally opposite consequences. For instance, popular just-in-time principle implies for small transportation batch sizes (Govindan, 2014). It by definition requires more frequent transport deliveries which lead to increased traffic congestion and environmental degradation. However companies are trying to make emphasis on practices which doesn't contain any environmental harm. So particular practices within abovementioned lean production such as waste elimination potentially leads to enhanced environmental performance (Govindan, 2014). What is interesting, some researchers argue that "green" SCM initiatives lead to improvements not only for environmental sustainability but also for economic one. For instance, waste elimination stands for the ability to reduce resource or capacity requirements through conservation and reclamation activities. Besides, the ability to capture resources for a cost that is less than the value recovered is promoted here. There is no doubt that cost reduction has enhanced companies' bottom-line performance through lean and sustainability initiatives.

Another topical issue in sustainable supply chain management (further referred as SSCM) is measuring its outcomes. As shown by Hassini et al. (2012), a wide range of social and environmental metrics are used by organizations, reflecting the breadth of topics sustainability can encompass in different organizations. However still the universe set of KPIs measuring sustainability performance in supply chains doesn't exist as the topic is very new.

Within sustainable supply chain management, circular economy is gaining more and more popularity as a concept (Witjes, Lozano, 2016). A circular economy has been recently proposed as a concept addressing both environmental and socio-economic issues. A circular economy primarily aims at transforming waste into resources and on bridging production and consumption activities. Supporters of circular economy concept argue that leakage of both biological and technical materials should be minimized by means of reusing and recycling (figure 1.2) not only for the sake of environment but also for gaining more efficiency impacting bottom line.

In context of business it involves development of more sustainable business models which are primarily based on aligning procurement process with principles of circular economy, in other words – sustainable sourcing (Genovese, 2015). Sustainable sourcing which includes careful choice of environmentally responsible suppliers and careful attitude towards recyclable resources. The essence of 3DP contradicts the principles of circular economy: basic raw material used for 3D printing is plastic which is non-biodegradable. Nevertheless today wider range of materials are becoming available for printing what probably will contribute to 3DP becoming more sustainable in this sense.

Figure 1.2 The scheme of Circular Economy concept



Source: McKinsey&Co., 2014

However, by looking at another important side of 3DP adoption – ease of transportation flows, we can conclude that mostly 3DP is considered to have a positive outcomes for sustainable supply chain management practices. 3D printing technology is considered to have a potential to revolutionize global logistics and transportation practices thus influencing environmental sustainability. Switching to digital flow of goods within supply chain management and logistics changes the core of the value. Ability to create CAD model (computer-aided design) and to send it online to any point of the world deprives firms of necessity to transport some very specific and complicated details or spare parts from another country and sometimes continent. There are no doubts that it leads to ease of global transportation flows and thus reduced the CO2 emissions.

One more important contemporary concept of SCM is connected with the role of digital technologies. Above there were brief mentions about digital and 3DP particularly, however we stop on it specifically since this is entire field which shapes the future of logistics in a great extent. It is widely considered that the role of digital technology is changing rapidly: from being a driver

of marginal efficiency to enabler of fundamental innovation and disruption (World Economic Forum report, 2016). World Economic Forum defined a few topics which are central to the concept of digital transformation of logistics industry:

1. Digitally enabled **information services** will elevate the role of data: data will become a core for logistics industry by means of logistics control towers and analytics as a service tools
2. Digitally enhanced **logistics services** will facilitate trade growth due to creation of digital cross-border platforms
3. New **delivery capabilities** such as 3DP will allow to disrupt traditional ways of transportation making delivery much more fast and efficient
4. **Shared logistics capabilities** will contribute to increased assets utilization

The following paragraph aims to look deeper at particular technological advancements which form the core of digital revolution of logistics and SCM.

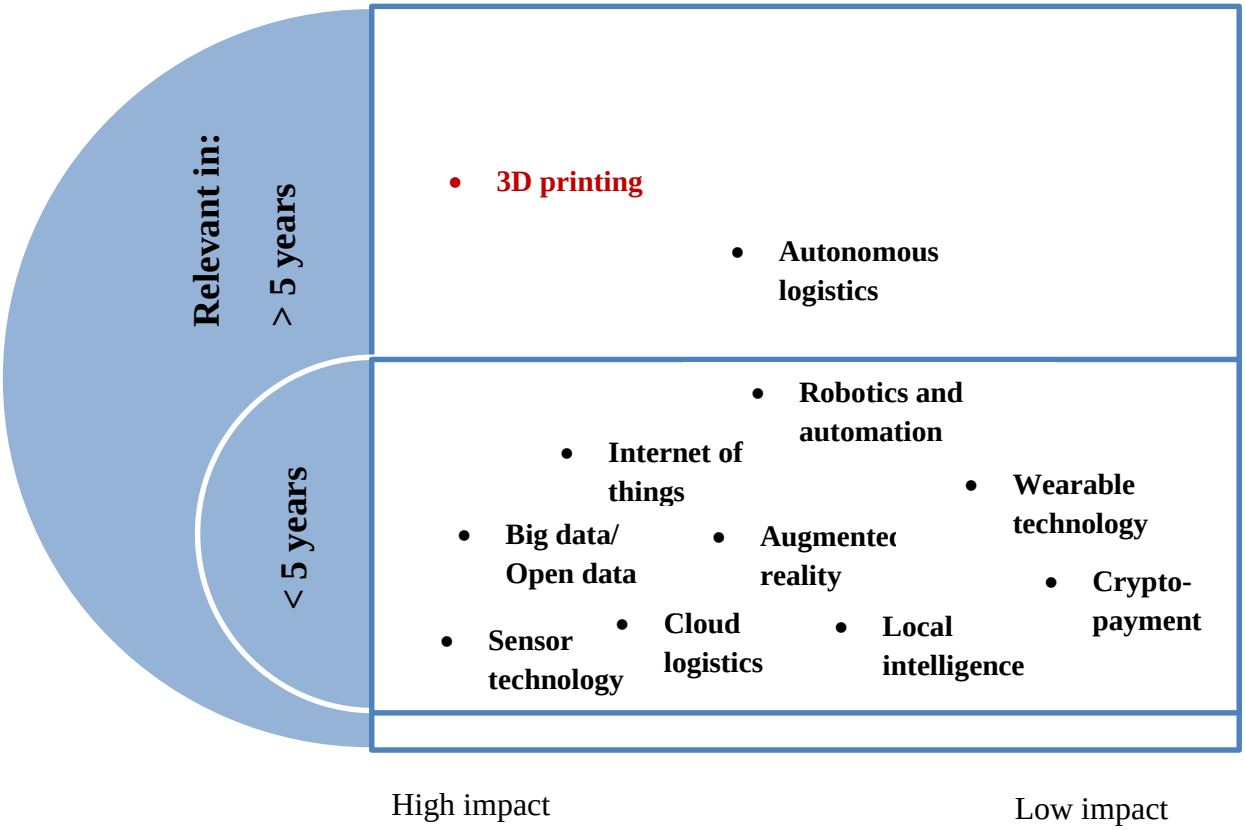
1.2. Big digital trends affecting logistics and SCM

Among the trends impacting the future of logistics and SCM in a great extent DHL underlined two groups: social and business trends and technology trends. Anticipatory logistics, de-stressing the supply chain and omni-channel logistics is among the trends encompassing the first group. Importance of the second group, technology trends, is rising sharply in last years. For the purposes of this particular thesis deep look at the group of digital trends is required.

Since last decade logistics and SCM industry has gained a lot of attention from both academics and practitioners. The perception of logistics and SCM has changed from being a supportive function towards becoming a primary activity according to Porter's value chain concept (1985). Dramatic enhancement of the role of logistics and SCM was caused mostly by globalization, expansion of MNCs and increased focus on responsiveness and cost-efficiency. Many leading companies' core capabilities are rooted in logistics and SCM superiority. That is why firms today are trying to achieve a competitive advantage in SCM by various methods. The important direction of enhancing logistics' capabilities is applying IT innovations. According to the famous industrial reports Hype Cycle (Gartner), Disruptive technologies (McKinsey global institute), MIT Technology review (MIT) and Logistics Trend Radar (DHL) intersection of logistics and key technological trends is in the spotlight today. IT advancements are called to be the main driver of shaping logistics and SCM area and in the next decade (figure 1.3). At the same time it represents the challenge for companies who will need to adjust the strategies in order

to catch up the wave of digital transformation. Below there is a review of technologies which are expected to shape the industry.

Figure 1.3 Technologies affecting logistics industry



Source: DHL Logistics Trend Radar 2014

Big data is one of the great opportunities utilized in many spheres. Generally big data means for accumulating extremely large data sets which are further analyzed computationally to reveal trends especially those related to human behavioral patterns. In its report related entirely to big data in logistics, DHL determines three majoe ways how big data are expected to be utilzed in the ways illustrated in table 1.1.

Table 1.1. The areas where big data may be useed for improving operational and SCM strategy

Big data for logistics and SCM	**Operational efficiency**	Real-time route optimization, crowd-based pickup and delivery, strategic network planning, and operational capacity planning
	Customer experience	Customer loyalty management, continuous service improvement and product innovation, and risk evaluation and resilience planning
	New business models	Market intelligence for small and medium-sized enterprises, financial demand and supply chain analytics, address verification, and environmental intelligence

Source: DHL Logistics Trend Radar 2014

Despite the fact that big data was considered as a very promising technology, the latest Gartner report places it into the stage of disillusionment (according to Gartner Hype Cycle) where publicity starts to see a lot of disadvantages in technology. Gartner claims that nearest years will be marked with switch from big data to **machine learning.** In some sense machine learning is similar to big data however it involves not only extraction of hidden schemes in data massive but also more sophisticated analysis of these schemes including own predictions.

The paradigm of cloud-based services is becoming increasingly relevant for logistics today. Applying **cloud logistics** helps to simplify supply chain from shipper to carrier to customer. Many firms already view cloud-based logistics as essential tool to get more value from operations. Ability to understand quickly the prices on any logistics element of the supply chain, controlling inventory in real-time, getting rid of multiple unnecessary software is viewd as a major benefits of cloud logistics.

Autonomous logistics utilizes innovations such as cellular transport systems, self-steering vehicles, and unmanned aerial vehicles (UAVs) that offer new transport and warehousing solutions, enhancing the efficiency of established assets and providing infrastructure alternatives in remote areas (DHL report).

Robotics and automation technologies support zero-defect logistics processes and enable new levels of productivity. According to DHL, newest advances in automated solutions with significantly improved performance and enhanced sensing capabilities offers a serious alternative to manual handling. Specifically, employing robots changing the paradigm of

operating warehouses. Last month German company Sigloch started to use robot which independently operates warehouse. It is expected cause dramatic reduction in warehouse management costs and number of errors.

Although **augmented reality** is in the early stage of adoption in logistics, it can offer a wide range of benefits. So far augmented reality has demonstrated the biggest value generation potential for warehousing. Immediate access to necessary information anytime and anywhere is able to optimize planning and execution of delivery and loading.

Crypto-payments fundamentally represents a new way of conducting business transactions around the world. Term "crypto-payment" underlined by DHL in 2014 now has transformed into the concept of **blockchain** which is debuting in context of SCM in 2016. At the Conference organized by Linux foundation companies like IBM, Cisco, Accenture and others made an arrangement to advance blockchain. According to IBM's press-release, "*blockchain is a digital technology for recording and verifying transactions. The distributed ledger is a permanent, secure tool that makes it easier to create cost-efficient business networks without requiring a centralized point of control. With distributed ledgers, virtually anything of value can be tracked and traded*". The application of this technology is already demonstrating a big promise in companies. Specifically to SCM, blockchain can accelerate the flow of goods and related payments and enable manufacturers to share production logs with OEMs and regulators to decrease product recalls.

Along with the abovementioned technologies **3D printing** deservedly takes one of the leading positions because its anticipated impact on logistics is expected to be truly dramatic. The following chapter will give an understanding of the state of 3DP market. We also will look at 3DP history, how technology actually works, what are its major benefits for enterprises and which constraints are still limiting 3DP from more widespread implementing.

1.3. Defining 3DP technology and state of the industry

3D printing refers to the field of digital fabrication which is also defined as additive manufacturing and rapid prototyping (Bogers et al., 2015). Originally used for rapid prototyping, 3DP technologies now are often part of manufacturing processes. Later in this research terms "three-dimensional printing" and "additive manufacturing" are used as synonyms for 3DP.

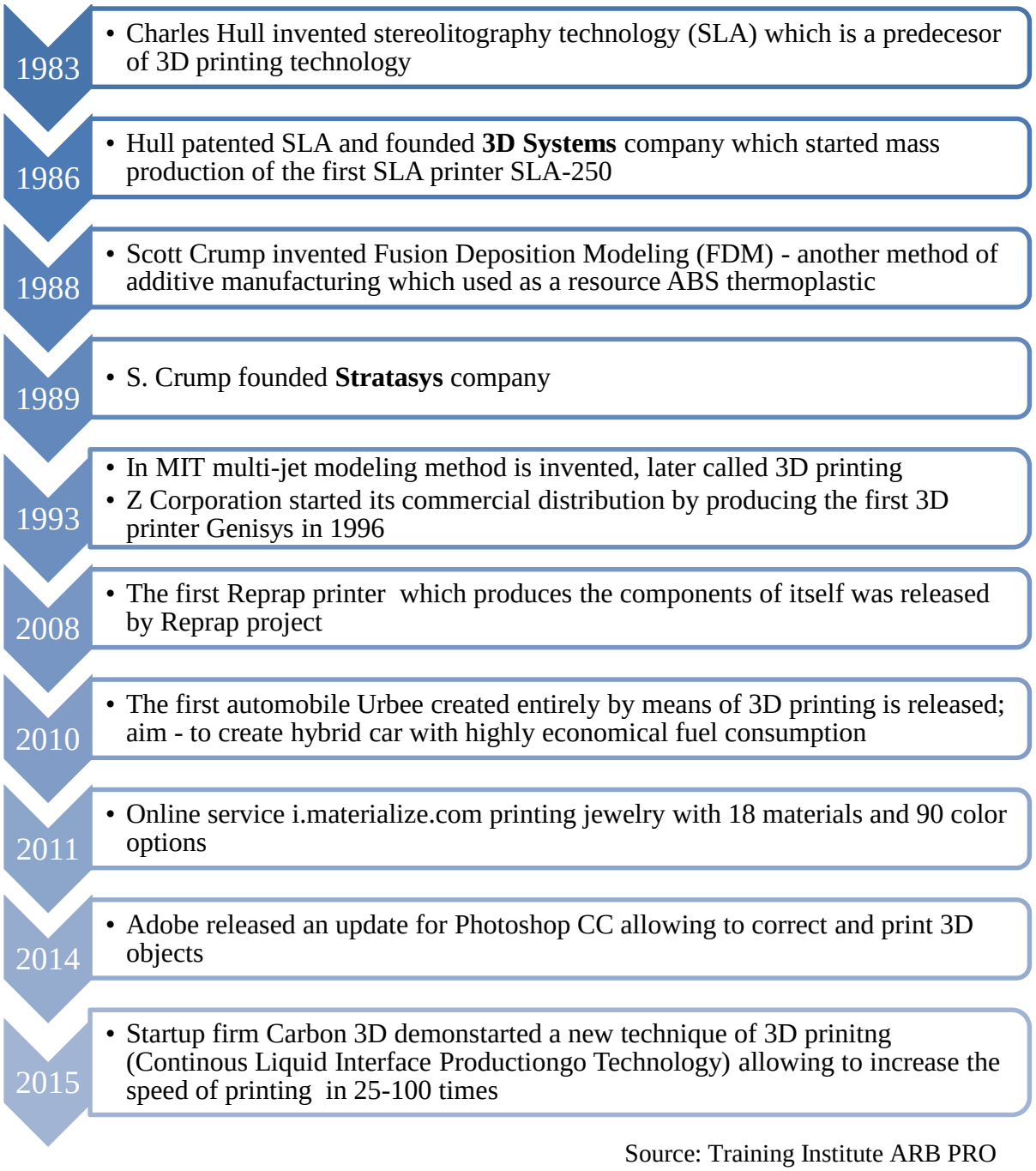
The technology behind 3D printers is similar to traditional laser or inkjet printers but rather than using multi-colored inks, the 3D printer uses powder that is slowly built into an image on a layer-by-layer basis. The more advanced hint in 3D printers is CAD software that

measures thousands of cross-sections of each product to determine exactly how each layer is to be constructed (C. Weller et al., 2015). As technology has been gradually improving, it developed from only being able to prototype to modeling and reproducing the separate objects.

Historical path of evolving the technology as well as the most important moments throughout its lifespan are illustrated in a figure below (figure 1.4). 1980th were marked with invention of the technology (SLA) and its advancements (FDM) which became predecessor of today's 3D printer. The opportunities of business application were recognized later, in the end of 1980th two leading players at the market of 3DP equipment were established: 3D Systems and Stratasys. Some manufacturing companies became pioneers and started to apply 3DP in their operational and manufacturing processes. Automotive was one of the first industries which started to exploit benefits of 3DP extensively. Ford Motor has been at the forefront of 3D printing and started to use technology in the end of 1980th. Today Ford prints the prototypes of many different car parts: engine covers, rotor supports, transmission cases, etc. Boeing started to use 3DP also relatively early, in 1997. According to Reuters (2016), today there are up to 300 different part numbers on 10 different aircraft production programs that are currently 3D printed[1]. This amounts to over 20,000 non-metallic additive manufactured parts that are currently on Boeing aircraft. However such a successful business cases were very rare and wide recognition that 3DP is a strong driver of improving operational efficiency emerged only in mid-2000th. There are some cases where 3DP is used mostly as a tool of extravagance or as "lifting the veil of secrecy" of how it will work in future. For instance, creation of the printer which is able to reproduce itself in 2008 or the automobile which is entirely printed. Eventually nowadays more and more firms deploy 3DP as a tool to improve operational efficiency and accelerate the supply chain.

[1] http://www.reuters.com/article/us-boeing-conference-idUSKCN0Y228W

Figure 1.4. The key milestones of additive manufacturing development

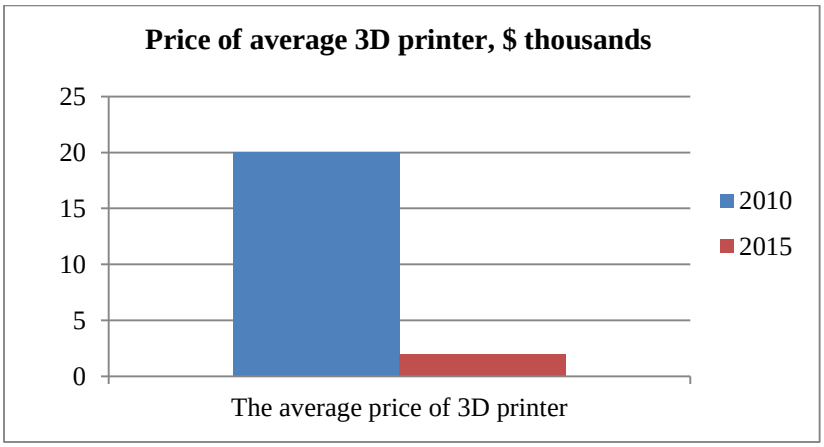


Source: Training Institute ARB PRO

1.3.1. Market overview

According to Training Institute ARB PRO, the market of 3D printing (equipment and services) accounts for $5,35 billion globally. CAGR for 2008-2015 is around 24 %. It is curious to observe how market growth actually exceeds the forecast. In the beginning of 2015 Gress (2015) forecasted the market of 3D printing to reach $5 billion in 2017. Despite the huge growth, industry still remains relatively small taking into account the age of the technology (Lagarde, 2015). So there is huge potential to grow, especially given the fact that awareness about 3DP rises and technology becomes more available and affordable (table 1.2). 3D printing gradually shifts the source of value for customers from possessing a final product towards owning a digital model of the product which can be printed. On average, 595 personal and 37 professional printers were sold every day in 2015. According to the different estimates, there are 50-70 producers of professional printers globally, more than 200 personal printers' producers and more than 190 manufacturers of printing materials. In the estimation of McKinsey Global Institute, 3D printing market contribution to the world economy is forecasted to be $230-$550 billion by 2025.

Table 1.2 Decrease in average price of 3D printer



Source: Training Institute ARB PRO

Geographically usage of 3D printers still remains concentrated. US is the leading country by 3D printers usage and is forecasted to save its leadership position and reach 42 % of global sales to 2017 (Wall Street Journal, 28 January 2014). The second largest market for 3D printers is Western Europe. Despite the obvious concentration in the most economically developed areas, important research centers are appearing along coastal Australia, in Brazil and throughout East Asia, especially noticeable researches occur in China.

By the application 3D printers are usually classified into two groups (ARB PRO 3D printing report):

- **Personal** – desk-top printers of small and average size priced < $3,000 and using mostly ABS plastics as printing material

- **Professional** – industrial printers priced > $5,000; possible printing materials include plastics, wax, liquid resin, metals, gypsum powder, etc. They are meant for companies with need of producing high-accuracy and high-quality models

As for 3D printing activities, the largest segment is remain to be prototyping – it accounts for 36,5 % of 3D printing activities globally. The second largest segment, hobby and "design it yourself" (DIY), captures 22,8 %. The next is scale model printing (10,8 %), gadget printing (9 %), art and fashion item printing (6,6 %) and household related printing (4,2 %).

As for the business application, 3DP has quite peculiar property – it can be successfully employed by firms from completely different industries and of different sizes (Brett et al., 2015; Tatham et al., 2015; Amit et al., 2012). However it is considered that industrial sector (especially aerospace, automotive and healthcare industry) have potential to employ 3DP with biggest benefits (ARB PRO 3D printing report).

In its annual Hype Cycle edition Gartner considers 5 steps of technologies' maturity:

1. **Technology trigger** – emergence of technology and start of its discussion among professionals and developers; the first publications in mass-media; emergence of the professional communities of professionals, enthusiasts and amateurs of the technology
2. **Peak of inflated expectations –** a lot of buzz around the technology, public agiotage leads to over-enthusiasm and unrealistic expectations; emergence of first firms trying to implement the technology and gain economic effect from it; building business on this stage is especially risky
3. **Trough of disillusionment** – the drawbacks of technology are revealed at this stage; overall disappointment about the technology; large percentage of technologies cannot overcome this stage
4. **Slope of enlightenment** – increase of cases of real business application of technology; emergence of adjusted and improved versions of technology; after a few successful cases of commercial implementation, the interest of media and public rises
5. **Plateau of productivity** - the technology gathers recognition and its place on the market, minimum 20 % of target audience starts to use it

These stages may be correlated with dynamics of market potential. So it is interesting to observe how the position of 3DP in this cycle has changed from 2010 (figure 1.5) to 2015 (figure 1.6). In 2010 3DP was placed in the first stage – technology trigger where its market potential hasn't been clearly realized. Five years later we see consumer 3DP in the beginning of trough of disillusionment stage but enterprise 3DP is already at the active phase in the slope of enlightenment. It means that market potential of 3DP increased significantly and has already been extensively used for last few years. Nevertheless being at the rise of "slope of enlightenment" phase stands for hidden market potential which hasn't been used yet. Thus according to Gartner Hype Cycle, 3D printing for enterprises has a rich market potential.

All in all, this maturity cycle clearly demonstrates that 3D printing is one of the fastest evolving and revolutionizing technology today.

Figure 1.5 Hype Cycle Emerging Technology as of 2010

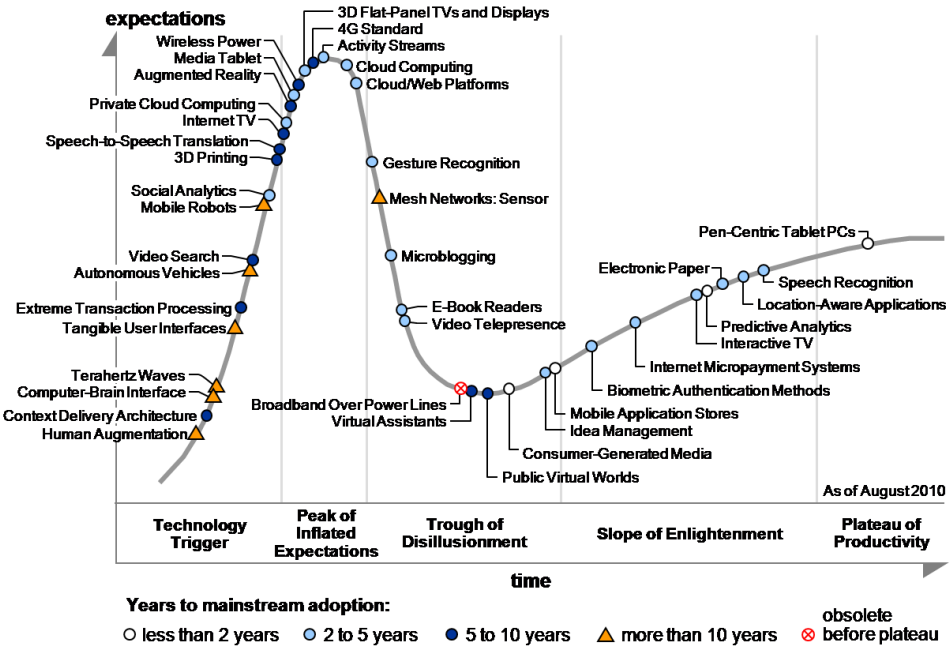
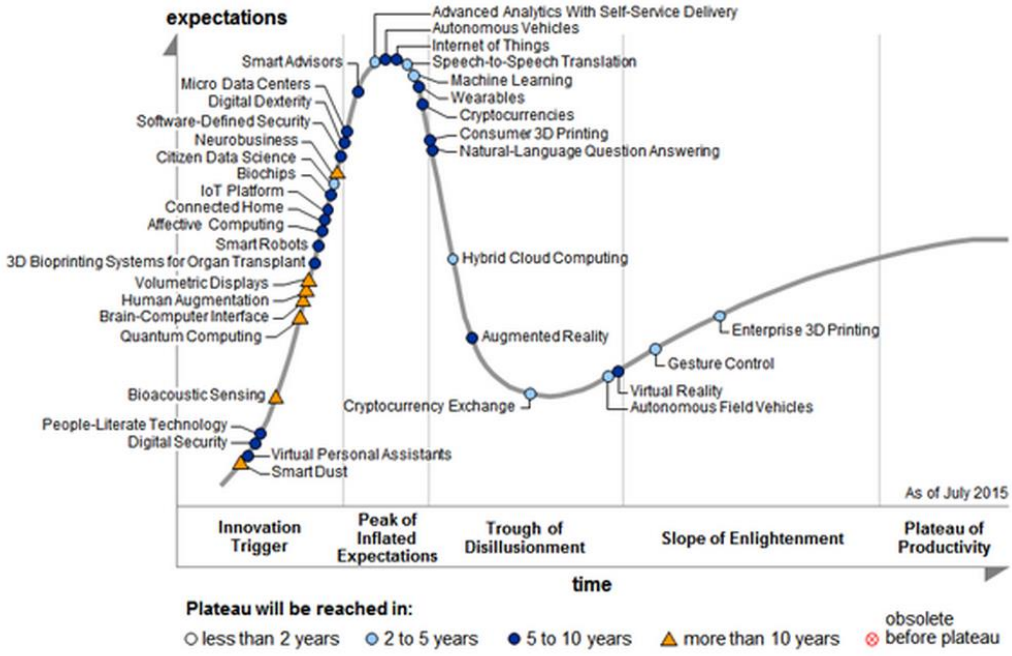


Figure 1.6 Hype Cycle Emerging Technology as of 2015



1.3.2. General benefits of applying 3DP

Despite the relatively small size of the industry and low penetration, more and more companies start to apply 3D printing technologies. Considering the fact that use of these technologies is quite expensive, the firms choosing to apply them, are teased with the benefits 3D printing brings. The field of additive manufacturing is principally analyzed within Supply chain management. The reason for that is not only disruptive effect on supply chains but also significant benefits connected with improving supply chain performance. Other advantages refer mostly to manufacturing, marketing, customer relationship or finance areas. Further two groups of effects of 3DP implementation are underlined: tactic and strategic. Tactic effects refer to the aspects of improving operational efficiency and enhancing the performance of supply chain without changing firms' underlying business models. Whereas strategic effects regard the shift of paradigm and switching to new business models.

Starting from the group of tactic effect, one of the most important advantages of 3D manufacturing is **lessening the complexity of supply chain**. The whole parties are becoming needless. Namely, manufacturers and suppliers of separate spare parts may lose their job because companies are gaining opportunity to represent these parts with 3D printer. For instance, Ford currently prints elastomer grommets and damping bumper parts for its Ford Focus electric vehicles instead of purchasing them from smaller supplier thus reducing the

supply chain. Besides, 3D printing dramatically decreases the lead time for the production of singe batches (Gibson et al., 2010).

Moreover, usage of 3D printing technologies allows to produce closer to customers thus entailing **higher responsiveness** to customers' needs. This implication together with high customization result in better relationships with customers.

Another important benefit is ability to **create unique products** (Franke, 2009). This opportunity is facilitated by both the CAD technology and participation of customers in production process. The former allows to design the most bizarre and fancy products and the latter is possible because of interactions between company and customers who are willing to take part in designing the special product. Moreover, additive manufacturing facilitates product innovation because of allowing design variations (Weller et al., 2015). The iterations with CAD software are fast, simple and not costly what generally accelerates and simplifies product innovation.

As for advantages for manufacturing, **high flexibility** is the most important one. Setup and switching costs are minimal. To reload the equipment for launching the production of another product only new CAD file needs to be uploaded (Weller et al., 2015).

Besides, some companies are tempted by cost-savings which 3D printing incurs (Perkins B., 2014). Usage of 3D printers in manufacturing process leads to **less transportation costs** as the opportunity to produce at one location appears. Together with ease of transportation flows **CO2 footprint is decreased** thus contributing to solving environmental issues to some extent. Moreover, reduced impact of manufacturing became possible with introduction of 3D printers instead of usual production techniques (Bosque, 2015).

Also this technology allows **to print very complicated parts** and objects at once thus skipping costly assembling and testing process. And in future the whole production and assembling shops may be replaced by 3D printing equipment **eliminating the fix costs** of holding and maintaining huge machines and assembly lines (Perkins B., 2014). Staff will be focused on monitoring the printers' performance and thus the need for some employees may disappear (Perkins B., 2014).

One more topical problem for business is solved by additive manufacturing. A lot of companies face **"scale-scope dilemma**" which contains the idea of huge increase in costs when additionally differentiating product (Lott et al., 2011). This problem loses its relevance when 3D printers are used for production. The possibility to influence the design from both company and customer side, is intrinsic when using 3D printers and doesn't bring any additional costs.

Switching to strategic advantages of 3D printing, ability to change business models by making them ideally adaptable and modular, is important advantage of 3DP. Some researchers believe that 3D printing technologies will be the foundation for the next industrial revolution (Jia et al., 2015). In such conditions, many companies are forced to think about adjusting or even reinventing their business models. Besides, the history has proved the fact that technological revolution without changing the business model is a pitfall for many business (Rayna et al., 2015). Business model describes the process and ability of organization to create and capture value (Rayna et al., 2015). Definition of business model includes 5 principal components: value communication, value proposition, value creation, value capture and value delivery. Rayna (2015) argues that further adoption of 3D printing technologies will definitely change some components of current business models. The major reason for that is the disruptive nature of 3D technologies which change traditional manufacturing processes (Bogers et al., 2015) in many businesses.

Many researchers had already investigated the forecasted impact of 3D printing technologies on business models' evolution. In general, the principal reason of influencing traditional business models is ability of 3D printers to lead to significant value creation (Rayna et al., 2015). The question, however, remains – how to transform this capability into competitive advantage. This question is vital for companies because possessing additional competitive advantage will most probably lead to increased perceived value of product in customers' minds. Subsequently it will enrich value creation component of business model. On the other hand, acceleration of production effects value proposition component because new products are released faster and more frequently. Rayna (2015) further discusses that bringing additive manufacturing technologies to the masses will make them more and more accessible. In its turn, this will allow companies to acquire the core competencies which they didn't have before (for instance, a smartphone accessories store might decide to get involved in smartphone case design or customization). Moreover, 3D printing may lead to the changes in value proposition because of access to great variety of design options.

Some of them argue that major shift 3D technologies bring to business is moving from traditional manufacturer-centric business model towards consumer-centric one (Bogers et al., 2015). This shift will be possible because of one very important property of 3D printing – underlying software which allows to differentiate the design. Companies started to interact with customers considering their most detailed wishes. Further implications of this property are needed to be discussed in a more detailed way.

3D printers use a software which allows them not only to prototype objects but also to design them. Thus one very important implication for business sphere is opportunity to

customize the product. The essence of customization allowed by using 3D printers is important to understand because this implication will be discussed and emphasized during the further research within this paper.

Some state that 3D printing enables firms to economically build custom products in small quantities (Franke, 2009) and thus they offer firms competitive advantage. However some researches don't recognize the uniqueness of customization offered by 3D printers and refer to simple mass customization. They argue that both technologies are capable to produce limited-amount lot sizes. But advocates of 3D printing technology still fend off stating that simple mass customization doesn't give such a variety of extra benefits offered by 3D printing. These additional advantages basically refer to manufacturing technologies and logistics requirements.

First, 3D printing uses a wider variety of raw materials including plastic, resins, nickel-based chromium and cobalt chrominium, stainless steel, titanium, polymers and even ceramics. Whereas mass customization is based on combining the details pre-assembled in advance and final product eventually will be manufactured of these ready parts (Franke, 2009). Second, 3D printers allow not only to prototype and design the objects but also to elaborate very intricate shapes of the products (Gress et al., 2015) what is not possible when applying mass customization. Besides, 3D printing mitigates the complexity of supply chain because no multiple suppliers of different spare parts are required (as it is in mass customization case). Finally, mass customization is often team-based whereas 3D printing is automated technique.

Thus the capability of additive manufacturing to highly customize the product leads many companies to build consumer-centric business model. The major strategic pillar of this model is direct interactions with customers which eventually result in highly customized products and satisfied customers. These interactions between manufacturer and customer have resulted in so-called *co-creation* – the process to which some research papers are devoted. Particularly, co-creation is named to be the important vector of user innovation and potential source of radical innovation (Rayna, T., et al., 2015).

Overall, 3D printing technologies enable business models to become modular and adaptable.

1.3.3. Business application

One of the researches stated fair question: "What other technology can get an artist, a medical clinician, an engineer and an environmental champion excited in the same way?"

(Hopkinson et al., 2006) This statement fully expresses how publicity and business community perceive three-dimensional printing technology.

The usage of 3D printing among different spheres is becoming so widespread that it's hard to find an industry where no one attempt to employ 3D printing was undertaken. Besides, it is interesting that completely different industries are applying 3DP – starting from consumer goods (including food, apparel, jewelry etc.) and finishing with strategically important industries like military-industrial complex.

One of the most important areas where 3D printing is used is medical care. Using three-dimensional printing for reproducing the medical instruments has become widespread. The printed medical devices can be found on surgical tables, in dentistry, on laboratory benches. Even biomedical engineering is already exploiting innovative technique. Moreover, Chimento (2011) has proved that 3D printing can replicate the performance of the plaster materials traditionally used in prosthetic/orthotic applications by using modified post process techniques. The particular value is that 3D printed molds are feasible for thermoforming prosthetic and orthotic devices such as prosthetic sockets while providing new flexibility.

Recently food industry joined the community of markets implementing three-dimensional printing. Particularly active in this area became chocolate producers. 3D printing allows companies to offer highly customized product (Jia et al., 2015) thus capturing growing market demand for personalized chocolate. Thus Jia (2015) conducted a first research on adopting 3D printing for producing food. Earlier investigations focused only on engineering and automation of equipment used in food industry (Millen et al., 2012 from JIA).

Apparel is one more example of industry which uses 3D printing. Pei (2015) in his identified the raw materials which when loaded onto printer produce the textile of high quality. This kind of material (polymer) displayed a high quality of print with good flexural strength. For the fabrics, woven cotton, woven polywool and knit it had excellent adhesion when the three polymers were deposited.

Humanitarian logistics is a very socially significant example of area where 3D printing may be useful. Tatham (2015) argues that in the regions which are traditionally prone to nature disasters, to set up a supply network in which the goods and services necessary to meet the needs of the affected population are delivered as efficiently and effectively as possible. The difficulty is to forecast the date and the scale of damages thus it's hard to hold amount of inventory which is needed. Three-dimensional printing comes to solve this problem because of opportunity to produce locally and because of dramatically reduced lead times.

1.3.4. Limitations and reasons of low adoption of 3D printing technologies

As any other innovative technology, 3D printing is not a panacea for manufacturing field and before it was demonstrated that relatively low percentage of companies are trying to exploit business opportunities arising from 3D printing. It is caused by a set of limitations 3D printing possesses. Analyzing the papers on limitations of 3DP technologies is especially relevant in context of this thesis. Understanding the verges, depth and ubiquity of factors restricting 3DP from widespread dissemination is crucially important. It will contribute to answering the main research question. Are there any inevitable limitations and constraints restricting 3DP from bringing truly disruptive changes to supply chain and logistics field.

All the researchers who investigated different aspect of 3D printing and illustrated its benefits, also discussed limitations of the use and adoption of this technology. The limitations discussed in different research papers are pretty the same thus it's reasonable to split them into a few groups which are presented below (figure 1.6). These groups represent the most significant and frequently mentioned factors stopping companies from applying 3DP.

The first group of constraints is connected with limited opportunities for differentiating manufacturing process when using 3D printers. For instance, available materials and choice of colors and surface finishes are still limited (Berman, 2012). Moreover, all the design opportunities offered by 3D printing remain limitedly accessed because of lack of experience and business case (Lagarde, 2015).

The second group of limitations includes the lack of qualified specialists to deal with 3D printers. As some stated, 'making' an object requires more than just a 3D printer and advanced knowledge of 3D modelling (CAD) software is still often required. Lack of technical knowledge by management and technical staff prior to the investment decision was also recognized as one of the deterrents of 3D printing dissemination (Mac Dougall et al., 2004). Besides, when company adopts 3D printing technology, the qualified general IT specialists are highly needed as the business benefits of 3D printing will be matched by some serious IT challenges. The folks in manufacturing, R&D and marketing who are most interested in 3D printing don't know much about evaluating how changes to day-to-day operations affect underlying IT systems. Most transactional systems will require major overhauls to support process changes in manufacturing and the supply chain. Many enterprises will also need to upgrade their IT infrastructures to support 3D printers. IT management must proactively insert IT's concerns about technology and costs into 3D printing conversations. In the research, held by Price Waterhouse Coopers, 45 % of small companies claim that they don't adopt 3D printing because of "lack of current expertise

within the company to exploit the technology or difficulty in recruiting talent" (Price Waterhouse Coopers, 2014).

The next set of limitations is comprised of quality issues. A lot of companies are doubtful about implementing 3D printing because of still unclear system of quality assurance. The precision of produced parts often needs improvement and global quality standards are still not established (Petrovic et al., 2010; Berman,2012). The consequences of this limitation may be very serious. Defective batches may be produced and sold because of lack of quality tests and absence of manual work (C. Weller et al., 2015). Potentially this can lead to the loss of reputation. It's interesting that when companies are asked about the reasons of not using 3D printers, about 48 % of them put "quality issues" as a the main problem stopping them from implementing it (Price Waterhouse Coopers, 2014).

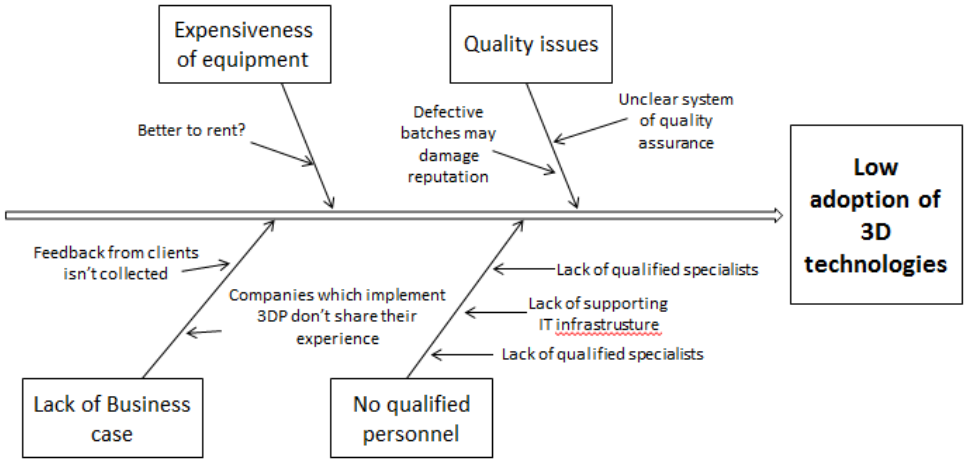
Another constraint is relatively low production speed compared to conventional production methods (Gibson, 2010). 19 % of small companies consider the small speed of production as the main constraint retaining them from implementing these technologies (Price Waterhouse Coopers, 2014). However 3D printers are becoming more and more advanced and the speed is increasing. And more recent research paper considers the speed of production as a competitive advantage of 3D printers if compared to injection molding or machine/subtractive technologies (Berman, 2012).

Some argue that generally technology is too immature to satisfy the high expectations it's facing from business and publicity (C. Weller et al., 2015). Moreover, Bosque (2015) states that 3D printing not only often feeds unrealistic expectations but also encourages unlikely hope about emancipation of consumers through self-manufacturing.

The next set of constraints include the general expensiveness of 3D printing equipment. Price Waterhouse Coopers report illustrates that large companies usually apply 3D printing significantly more often than small companies. When they investigated the reasons of such situation, around one third of small companies named expensiveness as a main reason of not using them (Price Waterhouse Coopers, 2014). General Electric hopes to print fuel nozzles for its new Leap jet engine. Current 3D technology can create a single-piece nozzle that is stronger and lighter than the existing nozzle, which is assembled from 20 separate pieces. Unfortunately, today's printers are too expensive for GE's purposes. However 3-D printing does not require expensive tooling, forms, or punches (Berman, 2012). Moreover some researches argue that significant expenditures may be paid back because customers are ready to pay extra for customized products (C. Weller et al., 2015). This tradeoff between expensiveness of equipment and extra value added which will make the price increase reasonable, is still unexplored by researchers.

All groups of constraints analyzed above represent the factors restricting majority of companies from active implementation of 3DP (figure 1.7). Some obstacles are especially relevant for specific industries. For instance, absence of unified quality assurance standards is crucial for medical equipment industry or any industry from military-industrial complex. As for markets representing consumer goods, general expensiveness of equipment may be important problem stopping companies from applying 3DP. Nevertheless, all these limitations are avoidable. In spite of these limitations being relevant nowadays, potentially they are possible to be mitigated or totally avoided in the nearest future. Generally speaking there are no truly ubiquitous constraints which may stop 3DP from disseminating and bringing dramatic effects.

Figure 1.7. Fishbone diagram illustrating the reasons of low penetration of 3D printing



1.4. Integration of 3DP and SCM practices

3D printing technology is often assessed as disruptive because its implementation causes significant changes in value chain. Particularly, supply chain field is going to be under the biggest impact. DHL states that there are two main ways of 3DP influence on SCM. First, for the established industries such as automotive manufacturing, life sciences or aero construction 3DP is becoming a supplementary way of both spare parts and final products production. From the one hand, this would add some complexity to supply chains due to rising necessity to orchestrate the logistics of parts produced traditionally and 3D printed. From the other hand, when companies are gaining some experience in dealing with 3DP, it would rather lessen the complexity of supply chain itself making some suppliers redundant and giving an opportunity to in a flexible manner.

Second, 3DP implementation encourages the windows of opportunity by creating new business models. These windows of opportunity may be exploited by almost any company

because of universal nature of 3DP. However, DHL particularly emphasizes the emerging niche for 3PL providers who will be able to extend their value chain by integrating new 3D capabilities into their end-to-end logistics services.

Deloitte University Press illustrates the possible paths of additive manufacturing development from the standpoint of impacting supply chain management (figure 1.8). Two axes are taken as a basis: level of product change and level of supply chain change. At the point of technology emergence and early development low product change and low SCM change observed, AM capabilities are only design and rapid prototyping. When the technology is becoming more widespread, it gradually leads to bigger changes in both product and SCM. Specifically, the development of additive manufacturing is expected to cause the significant shifts in supply chain management: manufacturing closer to the point of use, increase in responsiveness and flexibility, reduction in inventory level, supply chain disintermediation.

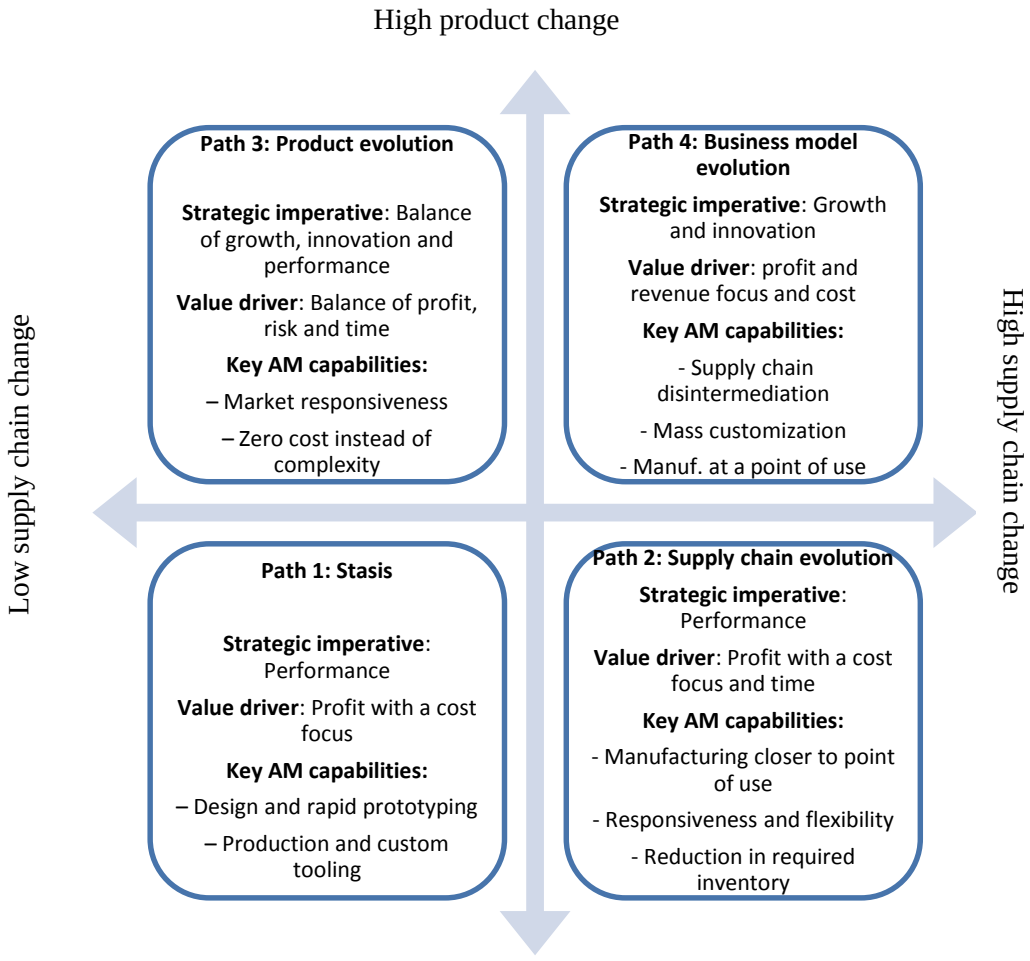
Downstream sections of the supply chain, such as production and distribution, are expected to have the most remarkable impact. The role of supplier, especially supplier of spare parts in different businesses, is expected to decline steadily and eventually to be fully eliminated. This will cause the shift from centralized to decentralized supply chain system (Bogers et al., 2015). Moreover, additive manufacturing is a hyper-flexible technology and it allows to produce highly-customized products. This, together with digital interactions during the manufacturing process, impacts relationship with customers (Bogers et al., 2015). As for general advantages, reducing the complexity of supply chains and shortening the lead time are named among the most important ones. Although in some cases 3D printing allows companies not only prototype separate spare parts by themselves but also to manufacture the whole products (Rayna et al., 2015). In these cases, eliminating the whole member in supply chain may be defined as a disruptive innovation and may lead to significant cost reductions. Besides, additive manufacturing technologies potentially increase manufacturing opportunities in remote locations by eliminating logistics difficulties of access to these locations.

However all these effects researchers described mostly hypothetically or by giving some exceptional examples. Thus it is unreasonable to spread ideas widely and generalize hypothetical effects. So if technology may be beneficially exploited only at very limited circumstances and for very specific company, its role and effect cannot be assessed as dramatic. Cases of real companies should be considered and carefully analyzed in order to approve or deny the criticality of effects brought by 3DP.

In order to prove or deny the critical role of 3DP for logistics and supply chain management, it is necessary to understand what kind of changes may be assessed as critical and revolutionary for this field. For this purpose measures of supply chain performance are recalled. the topic of measuring supply chain performance has been one of the most popular for

last years. Researchers investigated this topic in attempt to develop a new set of KPIs for measuring SC performance (Gunasekaran, 2004; Bhagwat et al., 2007). However all the indicators may be virtually divided into two big groups: costs and responsiveness. These two points are always seen as a primary KPI for any supply chain. Understanding the performance indicators of SCM is especially important for this particular thesis because to it is necessary for understanding to what extent the impact of 3DP may be critical for changing SCM practices.

Figure 1.8 Framework for understanding AM paths and potential value



Graphic: Deloitte University Press | DUPress.com

1.5. Research Gap

Extensive review of the state of the art has demonstrated that researchers not only from business area but also from IT, medicine, humanitarian logistics etc. are concerned with 3DP from different points of view. Various investigations regarding 3DP were performed by a researchers from all over the world.

However still all the studies are written in a manner of future perspectives. Researchers discuss the characteristics of 3DP and its potential ability to disrupt global manufacturing and supply chain practices. The lack of retrospective papers analyzing the performance of companies actively applying 3DP was observed. Moreover no investigations assessing criticality of the effect brought by 3DP to operations and supply chain management practices were found. Every new technology penetrates human's life and brings some changes usually sooner than previous. Author of this thesis argues that trying to assess the role of 3DP for SCM practices is well-timed already. Therefore research questions are the following:

RQ1: What is the direction of the changes brought by 3DP to SCM practices?

RQ2: Why these changes may become critical for shifting global logistics and SCM practices?

RQ3: What are the most probable scenarios of development 3DP in context of SCM practices for the nearest 5-10 years?

As shown in literature review, a lot of researchers demonstrated how 3DP may influence global business practices. However no one assessed the criticality and truly disruptive character of the changes brought to SCM practices. Moreover, this thesis is country-specific as it analyzes the cases of small- and medium-sized enterprises based in Russia. It also brings originality to this thesis because most of the papers devoted to 3DP considered economic centers like USA where innovative technologies traditionally developed faster.

Research gap exists in terms of both theoretical and practical aspects. From the one hand there is a lack of researches analyzing cases of real companies applying 3DP and comparing operational results before and after. From another hand, some contemporary SCM concepts seems to be contradictory to the effects brought by 3DP. In current paper complex approach integrating practical and theoretical aspects is used in order to bridge existing research gap.

Summary

Extensive analysis of the recent scientific papers and industrial reports revealed that today logistics and SCM are under the huge impact of social, business and technological trends. The role of the latter is rising dramatically due to introduction of latest digital innovations. 3D printing is considered to be one of the most promising technologies in context of shifting logistics and SCM practices.

3DP possesses a lot of advantages including lessening the complexity of supply chains, increasing responsiveness and flexibility, location of production closer to customer, opportunity to create unique product design and many others. Moreover, 3DP is a driver of switching current business model of supply chain management from physical flow of goods to digital one. Still it has many drawbacks including the expensiveness of 3DP equipment and lack of available materials for printing. These drawbacks prevent 3DP from widespread dissemination.

We looked at different frameworks illustrating how 3DP is actually able to shift logistics and SCM practices. The most comprehensive one created by Deloitte University Press (figure 1.8) states that highest level of 3DP integration into supply chain management will lead to total supply chain disintermediation, mass customization and manufacturing directly at the point of use. These consequences are very strategic and long-term. We saw that many experts talk about them but no researches examined the feasibility of attaining such stage. Thus the rest part of this research aims at revealing whether such a state is feasible and have any firms already attained it to some extent or not.

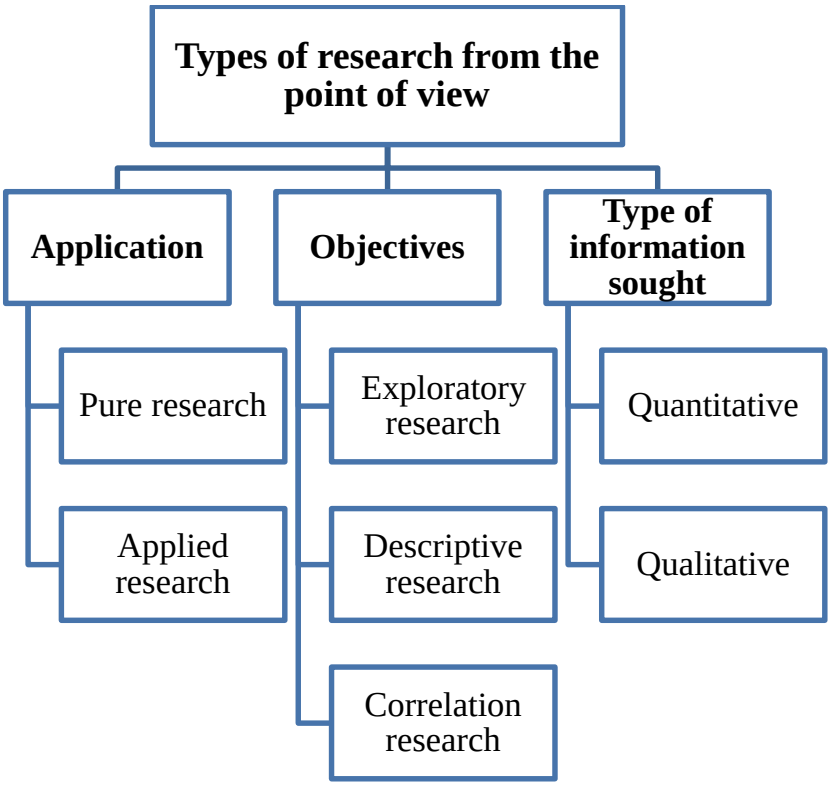
Chapter 2. Methodology

2.1. Nature of research

This chapter is devoted to the description of methods used in the research. Methods were chosen in accordance with the specifics of the investigated subject. The reasonability and relevance of the method applied is explained and justified. There is a range of available research

methods, however it is critically important that method should fit the nature of the problem and clearly answer the research questions stated.

Figure 2.1. Classification of research methods



Source: Churchill and Lacobucci, 2005

There are many classifications of research methods within business and management research field grouped by various characteristics (figure 2.1). So, Churchill and Lacobucci (2005) define three key groups of research methods by objective: causal research, descriptive research and exploratory. Causal research tries to investigate the cause and effect relationships, descriptive research aims at determining the relationships between variables, exploratory research emphasizes at discovering new ideas and specific insights within phenomena which is innovative or has not been extensively investigated before. The former also fits the situations when a very new phenomena studied or old phenomena analyzed from unusual angle.

As mentioned above, one of the main criteria when choosing appropriate method for research is its ability to answer the research questions and thus lead to desired results. Recalling the goal and research questions stated in previous chapter is useful in order to see which of the methods discussed fit the best to attaining the goal and answering research questions. Thus, the goal is to investigate the effect of 3DP on global logistics and SCM practices and to develop future scenarios of 3DP technologies development in context of SCM. The research questions are formulated in accordance with the goal: how 3DP implementation affects logistics and SCM

practices in companies (RQ1), why these changes may become critical for shifting logistics and SCM practices (RQ2) and what are the probable scenarios for development of 3DP technology in context of SCM (RQ3). The nature of research questions assume more open-ended and exploratory research especially given the fact that topic by itself is truly innovative. Thus due to the innovative nature of main phenomena analyzed in the paper, *exploratory* research is the most appropriate one according to the classification offered by Churchill and Lacobucci (2005).

Another basic classification of research methods is based on the type of data sought and splits research methods into qualitative and quantitative. It is considered that there is no difference in quality these groups of methods deliver but the major difference exists between the process of performing. According to Easterby-Smith (1991) behind qualitative and quantitative research methods two major paradigms lie – phenomenological and positivist paradigm respectively. The field of current research is supply chain management and logistics where quantitative research methods are traditionally more widely applicable than qualitative ones (Mangan et al., 2004). Mangan (2014) discusses in his study the advantages of combining qualitative and quantitative techniques in researches devoted to logistics & supply chain management. He argues the usefulness of using both groups of methods and proposes a framework to apply, which is called methodological triangulation. The essence of triangulation is in performing a few consecutive steps to ensure the validity of your research. The importance of triangulation is also emphasized by Yin (2002). However the topic of this research is exploratory and subject is still underdeveloped. It is considered that qualitative methods are primarily applicable in case of exploratory research. That is why there is no direct answer which method is better for this particular research. Moreover, the application of qualitative techniques normally doesn't exclude the use of quantitative ones.

To sum up, due to the contemporary nature of the phenomena investigated and lack of officially reported data from companies implementing 3DP, qualitative data is used mostly in this research. However after the main part of empirical research is finished, post-analysis in a form of survey is performed in order to back up the results gained.

2.2. Research Strategy

Table 2.1. Relevant situations for different research strategies

Strategy	Form of research question	Requires control or behavioral events?	Focuses on contemporary events?
Experiment	How, why?	Yes	Yes
Survey	Who, what, where, how many, how much	No	Yes
Archival analysis	Who, what, where, how many, how much	No	Yes/No
History	How, why?	No	No
Case study	How, why?	No	Yes

Source: COSMOS Corporation

When choosing the foreground research method it is crucial to consider the correspondence between the research problem, objectives and method. The goal of current research includes analysis and description of the consequences of 3D printing implementation. The essence of this goal implies mostly for qualitative explanation and if possible supporting measure of results attained by firms who use 3D equipment. Method which by nature includes mostly qualitative research but inside major qualitative data there may exist quantitative techniques is a *case study* method. Moreover, according to Yin (2002), research strategy based on case study is appropriate to apply when the research questions are open-ended and contain the "why" and "how" (table 2.1). Thus, the major research strategy for this thesis is *case study*. Moreover, the specific of 3DP technology is in its applicability in various companies regardless the size and industry. Thus in order to get a comprehensive view, we use *multiple case study*.

2.3. Research tools and validity

As Yin (2002) claims data may come from six different sources: documents, archival records, interviews, direct observation, participant observation and physical artifacts.

For this particular research primary tool within case study is going to be *expert interviews* due to the following reason. The specific of the subject investigated in this paper

requires direct communication with the firms applying 3DP. Basically we ask companies to reveal the practical insights of how 3DP is implemented in their companies. The peculiarity is that some firms may consider this information confidential and prefer doesn't disclosure it. That is why it is important to find people who are both enthusiastic and experienced enough in the topic and who are ready to share the insights face-to-face. To meet this requirements interviews is a useful tool due to being targeted and insightful research method (table 2.2). Besides, one of the research question is devoted to constructing probable scenarios for 3DP further development in SCM. In the conditions of lack of information, the insights and opinion of professionals who were on the forefront technology implementation, are truly precious.

However in order to attain triangularity and provide validity of case study research, minimum 2 of the methods should be used (Yin, 2002). Thus the second source to be used along with interviews is documentation (table 2.2). The set of documentation analyzed includes press-releases, industrial reports, annual reports, articles appearing in mass media.

Virtually empirical research is divided into two parts: primary multiple case study and supporting analysis. The first one includes conducting expert interviews and analyzing relevant secondary sources, what comprises case study method application. The supporting analysis is introduced in order to backup and validate the insights uncovered during the case study research.

Table 2.2. Strengths and weaknesses of the sources of evidence

	Strengths	Weaknesses
Documentation	- Stable – can be reviewed repeatedly - Unobtrusive – not created as a result of case study - Exact – contains exact names, references and details	- Retrievabillity can be low - Biased selectivity - Reporting bias - Access
Interviews	- Targeted – focuses directly on case study topic - Insightful – provides perceived causal inferences	- Bias due to poorly constructed questions - Response bias - Inaccuracies due to poor recall - Reflexivity – interviewees give what interviewer wants to hear

Source: Yin, 2002

2.4. Expert interviews and survey design as post-analysis

Conducting interviews with professionals having an expertise in the topic is a useful research tool. The purpose of conducting expert interviews for this thesis is double-sided. First, it aims to uncover the effects 3DP bring to companies operations and SCM practices. Second, experts' forecasts regarding the scenarios of development of 3DP in the frames of logistics and SCM are expected to be gained. For this particular research 13 interviews have been held. The selection of experts for interviews was very rigorous. A few criteria for an expert to be selected as a respondent are the following: minimum one year of expertise in dealing with 3DP, permanent job is connected with 3DP, respondent's opinion has been cited in professional sources (journals or web-sites devoted to 3DP). Moreover, among the group of professionals participated in an interview there are corporate and academic professionals. Corporate people are presented with both companies selling and providing 3DP services and companies from different industries applying 3DP in their activity. Professionals from the corporate world purposely represent different industries in order to obtain more extensive and full view of the methods of 3DP application. Specifically, representatives from both industrial and consumer sectors will share their expert opinions. What is more, for increasing the relevance of the analysis, representatives

of companies with negative experience in applying 3DP were also selected as participants. As for academicians, head of University department entirely devoted to development of additive manufacturing technologies, is among the interviewees. We believe that such an extensive and promiscuous group of interviewees will let us to uncover more valuable insights. Professionals from corporate world were initially approach in a different ways: directly by means of email or phone, with a help of University career center or Cyberon group, company selling and providing 3DP services.

If analyzed according to Hype cycle emerging technology (figure 1.5), in the world 3DP technology development is currently at the slope of enlightenment stage (4th out of 5). However if talking about Russia, 3DP is most probably between the technology trigger (1st out of 5) and peak of inflated expectations stage (2d out of 5). It implies for absence or lack of required data to analyze actual technology's potential and capabilities. In such conditions, gathering the opinions of people who are actively engaged in technology implementation and dissemination, is an important step for gaining insights straight from the horse's mouth.

In order to design interview script which is the most appropriate for this thesis, 3 types of interviews for gaining research data are analyzed below.

- Structured

When the questionnaires with standardized and rigorous set of questions are used and the interviewer reads the question and record answers. This type of interview is mostly used for the collection of the quantified data and often this kind of interviews is called quantified interview (Saunders, Lewis and Thornhill, 2007).

- Semi-structured

Such a type of interviews allows to note preliminary set of topics to be covered. Semi-structured interview is open, allowing new ideas to be brought up during the interview as a result of what the interviewee says.

- Unstructured or in-depth

In majority of cases this kind of interview represent a free conversation on one or a few particular topics. It is important for interviewer to have a clear understanding of this topic however.

For this particular research semi-structured interview approach seems to be the most appropriate. It may allow to reveal some important practical insights that are impossible to anticipate in advance and include into the set of questions. During structured interviews the depth and breadth of conversation is limited because of necessity to answer specific frame of questions. As the topic of this research is innovative and exploratory, it will be useful to get any insights from people who are specializing in this topic. As it was stated above, experts selected

as interviewees in this research represent different industries and different organizations. It makes structured interviews barely possible because of slightly different expertise areas. Nevertheless all the professionals are working with 3DP technology thus it makes sense to mark the areas important to cover. As Fisher (2014) highlights, there are a few important steps of preparation for semi-structured interview:

1. Roughly sort and list areas of questioning
2. Edit and prioritize questions
3. Consider methods that will be used to analyze questions
4. Put questions into sequence
5. Check the questions for relevance for the research topic

Although these actions seem to be obvious, they should be performed because interview in this context is a specific research tool which needs a clear organization. Since semi-structured interview design was chosen as a primary type of interview, the first task is to define particular set of sub-topics to be covered. Semi-structured interview gives a flexibility in formulating exact questions from one interview to another while still covering necessary topics. When coming to the stage of designing the interview, we have already conducted the literature review and able to identify some insights for further testing during the interview phase. Thus questions were asked during the interviews in accordance with the following set of topics, relevance of which was revealed during the previous research step:

- when did your company start to apply 3DP technologies?

- how does your company apply 3DP technology?

- what was the initial incentive to use 3DP?

- what are the competitive advantages 3DP brings?

- what are the changes brought by 3DP to company's operations?

- was your company able to reduce the supply chain because of opportunity to stop ordering some details or spare parts from a supplier?

- what are the main constraints stopping 3DP from mass implementation by companies?

- what is the probability that 3DP will be used at a mass level by companies?

- what are the probable scenarios of the development of 3DP technology for nearest 5-10 years in terms of impact on logistics and supply chain management?

These questions form the basic interview structure. In majority they are formulated in a rather specific way in order to uncover necessary insights for answering research questions. However depending on time availability and readiness of the interviewees to reveal some

particular issues, the set of questions asked during the interviews was in some cases slightly adjusted. Interviews were conducted both by phone and face-to-face due to different location of people selected as interviewees.

Survey

Survey research is a tool used to collect information about a sample drawn from a well defined population of persons, households, or organizations, according to Patrick and Hardigan (2016). It provides researchers with an opportunity to collect valuable primary data. Although alternative tools such as observations, panels, focus groups, and interviews may provide, in some cases, superior information. As any research method, survey possess specific advantages and disadvantages (see Table 2.3).

In this particular thesis survey is used as a supporting tool to backup the conclusions derived during the primary empirical research – case study. The survey was chosen to be a validating instrument in this research due to three main reasons. First, in order to backup and validate the data gathered during the previous empirical step, expert interviews, quantitative data is highly required. Second, there is a lack of officially reported data by companies applying 3DP due to innovative nature of technology. Some companies are just experimenting and prefer not to claim it officially. Indeed, preliminary research during the literature review and expert interviews gave us a reason to consider that there is some amount of companies implementing 3DP but not claiming it. Online survey gives a company's representative opportunity to maintain confidentiality while still indicating other important data about the firm. The third reason is connected with opportunities to analyze data derived from the survey statistically. Due to lack of another sources of quantitative data regarding 3DP implementation in companies, survey is a precious opportunity to assess whether 3DP is truly changing SCM practices and to prioritize the effects brought by 3DP.

Table 2.3. Advantages and disadvantages of a survey as a research method

Advantages	Disadvantages
High representativeness	Inflexible design
Low costs	
Convenient data gathering	Not able to deal with controversial issues
Avoidance of observer subjectivity	Possible inappropriateness of questions

The survey is purposely installed in this research after expert interviews because it aims at testing and validating information gathered from experts at a bigger scale. Designing the survey was also conjugated with the previous research. Namely, based on expert opinions, the options for some questions in survey were derived. The survey consists of three blocks. The first block is devoted to introductory questions, the second includes questions about firms' experience with applying 3DP, the last set of questions devoted to personal estimation of the role of technology. Full survey script is in Appendix 1. There are 3 types of questions used in the survey: multiple choice questions, open questions and scale questions. For designing a scale questions Likert scale was taken as a basis because of its reasonability for use in survey researches.

When designing a survey it is crucially important to understand who are the target audience. As for our survey, target respondents are most probably people working either in production or engineering department of companies operating in different industries including both industrial and consumer sector. These companies either used before or still working with forms providing 3DP services and selling 3DP equipment. They were selected for filling the questionnaire because of being in the client base of 3 biggest 3DP equipment and services providers in Russian market – Cyberon group[2], 3Dvision[3] and RUBOT[4]. These people most probably doesn't spend the majority of time in front of their computers. In order to catch and hold the attention of these people to our survey, it is intentionally kept quite short while clear.

By means of survey we suppose to obtain the following data:

- the most influenced by 3DP areas of firms' performance

- the reasons of 3DP adoption

- the effects brought by 3DP to various companies

- whether the strength of effect brought by 3DP is different for companies operating in industrial and consumer sectors

- whether the beneficial effect of 3DP is different for firms of different size

- which sector – industrial or consumer goods has a potential to employ 3DP in a more beneficial way

[2] http://cyberon.ru/
[3] http://3dvision.su/
[4] http://www.rubot.org/

Eventually based on the statistical analysis of the data from survey, a decision tool demonstrating the feasibility and reasonability for companies to apply 3DP technologies, is elaborated. The factors such as company's size, type of industry, the period of applying the technology are included in the survey intentionally to be able to develop recommendations for the companies making a decision about worthiness of applying 3DP.

2.5. Data collection

In order to comprise case study, relevant companies were found. It was decided first to approach the companies operating as experts in 3DP industry. Normally such a companies are both suppliers of 3DP equipment and providers of 3DP services. Biggest companies having a branch in Saint-Petersburg were defined. These companies include Cyberon, 3dvision and RUBOT. Companies' CEO's and managers were engaged in the interviews, provided the author of this thesis with contact data of their clients and helped in survey distribution to potential respondents.

The first firm in the list, Cyberon, operates in 3D printing industry on Russian market since 2014. It has three established branches – in Moscow, Saint-Petersburg and Kazan'. Providing range of 3D services to small and medium-sized companies is a primary activity for the company. Cyberon's customers include mostly small and medium-sized companies operating in different industries. The interesting moment is that Cyberon's customers are different because the specific of business let company not to be limited only with clients operating in some businesses. Among Cyberons' customers there are firms operating in chocolate production, air conditioning systems, jewelry, meat production, breadboarding and other industries.

Another enterprise to be used in the research is 3dvision. Company was established in 2012 and specializes in collaboration with industrial and construction firms.

RUBOT, LLC is another company providing 3DP services and selling 3DP equipment. RUBOT, established in 2010, was one of the first companies in Russian market which started to popularize 3D printing. Among their clients are various companies operating in electromotors construction, industrial lubricants' production and dish and food production.

Based on the market analysis and the interviews with abovementioned firms, the industries where 3DP is used very extensively and expected to bring biggest gains were identified. After that, a sample of companies representing identified industries was comprised. Companies were initially contacted either directly by email or via 3DP distributors.

2.6. Limitations

The phenomenon investigated in current thesis is very innovative. Active implementation of 3D printers in Russian companies has started around a year ago thus it is impossible to derive enough time-series data for computing any kind of mathematical or statistical model. The ability to construct model is important in terms of proving existing correlations and interconnections. For this particular study statistical model could be potentially useful in terms of demonstrating the effect 3D printing technologies have on performance indicators of company. However the specific of constructing time-series statistical models doesn't allow to use them in this particular study. Necessary condition for computing time-series model is to have at least a few time periods during which investigated phenomenon could affect some performance indicators.

Moreover, there is still only limited amount of companies in Russia who implement somehow 3D printing technologies. Thus the task of constructing regression models and measuring the correlation between the operational performance and usage of 3D equipment becomes very complicated. The sample to be used in constructing regression model has to be of definite size. Generally it is considered that minimal sample size is 30 observations but 30 is a minimum limit and the quality and reliability of such a model may be arguable. By means of survey this problem is partially solvable however even the task of collecting at least 30-40 responses is complicated and doesn't guarantee the total representativeness.

One more limitation relevant to this study is absence of scientific theories on the topic. As the subject is innovative, there is no underlying scientific theory behind.

Summary

Information presented in this chapter refers to the methodology and research design which will be used as a basement for this thesis. The primary research strategy is multiple case study. Because the nature of investigated topic is exploratory, the topic itself is innovative and the technologies are applied actively only for one year, the qualitative and quantitative research methods are to be combined. We argue that for this particular thesis combining qualitative and quantitative techniques is relevant due to the nature of investigated issue. Qualitative tool is appropriate for this research because the topic is exploratory and quantitative is also suitable

because of mostly quantitative nature of the studies in supply chain management and logistics field.

The first step in collecting empirical evidences is performing case study itself by conducting expert interviews and simultaneously analyzing documentation related to the issue studied.. The set of companies chosen for case study is represented by professionals permanently working with 3DP and representing both corporate and academic world are chosen as interviewees. Semi-structured interview design is applied in order to gain more valuable insights while covering the predetermined set of topics. The supporting step of research is conducting survey. The insights gained during the literature review and case study served as a factors to test in survey. Eventually the results obtained during the empirical phase aim at both answering the research questions and constructing an applied decision-making tool for companies thinking of applying 3DP.

Chapter 3. 3DP implementation: evidence from Russian companies

This chapter aims to demonstrate the results of empirical study conducted in order to provide a comprehensive analysis of the issue. Multiple case study is double-sided and from the one hand includes analysis of six companies implementing 3DP, from the other hand it includes evidence from three leading 3DP distributors in Russia. We included both buyers of 3DP equipment/services and its sellers intentionally to see how the perceived role and value of technology differs. It is also curios to see how 3DP distributors think their clients perceive the role of technology and then to see from the clients' side how they truly view 3DP.

These companies implementing 3DP were chosen specifically to represent different industries and have at least one year of experience in implementing 3D printing in their primary activity. Interviews were conducted either with CEOs or with heads of construction or innovation departments who disclosed some important insights for answering the research questions. As for 3DP distributors, leading firms operating in Russian market were considered. Besides, we organized a few back-up interviews not being directly related to the companies however extremely helpful in constructing the full picture. These interviews were conducted with analyst-consultant specializing in the topic of technological innovations and the head of additive manufacturing department at Samara State Aerospace University. I do believe that gaining as much information as possible from various parties involved is extremely helpful when examining contemporary phenomena.

In order to achieve triangulation when analyzing case study multiple sources were used. So expert interview is a primary research tool while companies web-sites, industrial reports and press-releases are also analyzed to obtain more comprehensive view. As it was underlined above, the topic is exploratory and investigating this issue should be started from gaining expert opinions. For comprising the understanding of the role of 3DP and constructing the vision and future scenarios of 3DP technology development, accurately selected respondents shared their opinions. At the same time documents and publications were scanned for evidences supporting, contradicting or complementing the insights from interviews.

After that post-hoc analysis in a form of survey was performed – some insights were taken as a base for constructing the survey and testing these insights by means of survey.

This Chapter is organized as follows: the presentation of companies included in case study, presentation of the results reported by companies and eventually discussion and analysis of this results in context of impacting logistics and supply chain management practices.

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3.1. Presentation of cases

Before coming to the description of empirical investigation, there is a brief overview of the companies involved in the case study analysis. As mentioned before, case analysis consists of examining two groups of companies: firms implementing 3DP technology in their primary activity and firms-distributors of 3DP equipment and services.

Venera, LLC is a small jewelry producer based in Saint-Petersburg and established in 2007. Company was founded by 3 friends, professional jewelers. Its turnover and client base not very extensive however the main pool of clients is composed of repeated buyers who value customized approach cultivated in company and the quality of jewel. The permanent staff consists of 15 employees, there are also freelance jewelers working for company from time to time.

Technodinamika, JSC is a holding involved in aviation units, power supply systems and parachute systems. Founded in 2009, Holding is comprised of 36 smaller firms. Research and development work is crucial for the company's growth. Its entities, design bureaus and research institutes invest significant funds to boost innovation, research and development. Holding focuses on the development and production of units, devices and systems in eight core areas: units and engine control systems; life support systems and emergency systems; control systems and executive devices; hydraulic and fuel systems; power supply systems and switch gear; auxiliary power systems; service and maintenance equipment for airports and lighting gear. Entirely all the companies within holding employ around 30,000 people.

Massa-K, CJSC is a producer of electronic scales for industry, commerce, medicine. Established in 1991 in Saint-Petersburg, firm exports significant part of its scales to almost 30 countries. Among its product range there are merchant electronic scales, crane scales, rampant and palette industrial scales, bench-type scales, medical and laboratory scales. Company employs approximately 200 employees.

Petrotech, CJSC is a manufacturer of fixing systems and fastens established in 1993 in Saint-Petersburg. Currently company is supplying large retail chains, architectural and civil engineering companies as well as development laboratories. Staff number is around 60 people.

OKB-1 (Ob'edinennoe Konstruktorskoe Buro), JSC operates as an engineering bureau manufacturing details and spare parts for industrial equipment and vehicles. Company was established in 1995 in Saint-Petersburg. There are belt transmission, rotating crank, rack-and-

pinion actuators among the mechanisms produced. Besides, company manufactures parts for military-industrial purposes like target cards. Firm currently employs up to 50 people.

Ahlers, LLC is a third-party logistics provider originated in Belgium in mid-1950th. Today company offers supply chain optimization, maritime and logistics services. Its first branch in Russia, Saint-Petersburg was opened in 1993 and has a strategic meaning for company. Staff number is about 2000 people.

Below there is an overview of firms producing and/or distributing 3DP equipment and providing 3DP services.

RUBOT, LLC is a firm providing 3DP services and selling 3DP equipment including their own printer. Company G, established in 2010, was one of the first companies in Russian market which started to popularize 3D printing. Among company's clients there are various companies operating in electromotors construction, industrial lubricants' production and dish and food production. There are 14 people working in the company.

Cyberon, LLC operates in 3D printing industry on Russian market since 2014. It has three established branches – in Moscow, Saint-Petersburg and Kazan'. Distributing 3DP equipment of famous brands and providing range of 3D services to small and medium-sized companies is a primary activity for the company. Firm's customers include mostly small and medium-sized companies operating in different industries. The interesting moment is that firm's customers are different because the specific of business let company not to be limited only with clients operating in some businesses. There are firms operating in chocolate production, air conditioning systems, jewelry, meat production, breadboarding and other industries among company's clients. The amount of personnel is about 50 people.

3DVision, LLC is a provider of 3DP services and specializes in collaboration with industrial and construction firms. It was established in 2012 and currently employs 65 people.

Except for the representatives of companies described above, the data was gathered from other experts in the field of 3D printing. Interviews were organized with representative of academic institution because the technology becomes so increasingly disseminated and promising that some Russian universities open the departments entirely devoted to additive manufacturing. Considering such a case is especially interesting because often such departments work under the support of Russian government and collaborate directly with some enterprises possessing strategic meaning for our country.

Another point of view is gained from analyst-consultant of the small consulting agency ARB Pro Training Institute, based in Russia and established in 1993. This firm recently performed deep and extensive market investigation and is well-aware of how the usage and perception of 3DP is actually evolving. This interview represents a particularly valuable insight because opinion of consultant about the role and future of 3D printing is multi-faceted, comprehensive and is not narrowed down to the specificities of 3DP application in particular industry. In other words, after examining the data from particular companies, opinion of consultant who possesses the view of bigger picture is like a touchstone.

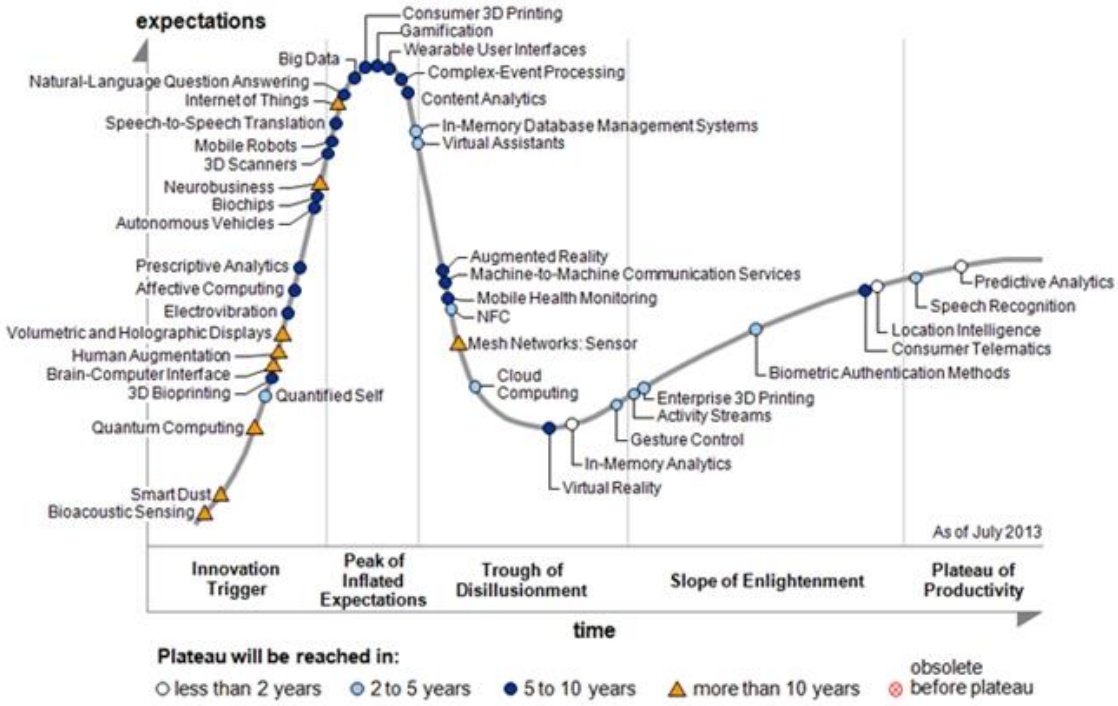
3.2 General insights

The advantage of the sample of companies in this research is its ubiquity: companies are from different industries and of different sizes. Such a sample was formed intentionally to demonstrate peculiar nature of 3DP technology: it may be applied in any company which has manufacturing stage. Although being different in terms of industry and size, all firms actively apply 3DP in their primary activity.

Almost all the experts participated in the interviews were quite enthusiastic and shared some insights and personal forecasts regarding the development of technology. Companies' representatives (further referred as "industry experts") gave more specific insights about implementation of 3DP and its role for their particular industry. In contrast, experts from companies selling 3DP equipment and providing 3DP services (further referred as "3DP experts") to a wide range of firms, looked at the situation in a more general manner. The latter possess a valuable market insights because of opportunity to observe the dynamics of the interest companies demonstrate towards 3DP.

All the companies started to implement 3D printing in their activity from 1 to 3 years ago. Indeed, according to Garter Hype Cycle technology (figure 3.1) as for 2013 3D printing for enterprises entered the slope of enlightenment stage which is characterized by increase in the number of successful cases of real business application approximately 3 years ago. There is only one firm which reported the time of applying technology significantly more than others. Company C, producing electronic scales has been using 3D printing for almost 10 years already. It is probably explained by operating in quite science-consuming industry thus employing people with a deep R&D expertise who are normally aware of the newest technological trends.

Figure 3.1 Hype Cycle Emerging Technology as of 2013



What is for areas of implementation, firms reported using 3DP at both R&D and manufacturing stage. Companies named more or less the same advantages and principal changes brought by 3DP to firms' activities. However it was noticed that depending on the size and industry firms emphasized different effects of 3DP which they consider a main reason of using 3DP. Similarly, firms named different drivers which made them to implement 3DP.

The important driver brought by 3DP implementation was stated by firms from industrial sector: accelerating and technologically enhancing the process of new product development (NPD). This feature was also underlined in a press-release of company B and assessed as very important. Along with accelerating, companies named advancing and enhancing of new product development and construction processes which allows to improve some technical characteristics of industrial parts, engines and different mechanisms. Most of them also use 3D printing for prototyping of parts and the entire products. Companies B, C and E operating in industrial sectors claimed that prototyping details by means of 3DP is a unique opportunity to determine the flaws in construction design and eliminate them before launching a mass production. Indeed, Wohlers (2015) mentioned that up to 70 % of the cases of 3DP implementation are connected with prototyping.

Considering another advantages of applying technology, most often interviewees recalled reduction in costs and lead times. It is supported by the results of analysis presented in DHL Trend Radar Logistics report. It demonstrates that most companies realize the importance of 3DP principally at operational level and doesn't consider the technology to be a source of potential

disruptions at strategic scale. Nevertheless experts from some companies highlighted the effects of 3DP different from the majority of other respondents. So, Company A marked unique opportunity to create product designs which before were impossible to bring into reality. Thus it seems to be logical to investigate further on which characteristics the effect brought by 3DP is dependent. The preliminary ideas derived from the respondents' answers gave a reason to test whether the effect from 3DP depends on the company's size, time of applying 3DP and industry. We will further test this assumption by means of backup analysis in a survey.

As for the perceived value and principal role of 3DP, all experts agree that the role of 3DP is important for their firms. Nevertheless they don't perceive the technology as disruptive since they use it mostly as a helpful tool in production bringing certain advantages. Most of the companies assess 3DP as a tool simplifying and enhancing their manufacturing capabilities. They don't view the impact brought by 3DP as strategically important and don't really assess its future potential as significant. Mostly companies were quite positive about the future perspectives of technology development in general. However when it came to their company, they didn't show any strategic intentions predicting that firm will continue to use 3DP as they do it now. The reasons for this were various and specific for each company. Probably that was due to bias of interview approach. The technology is innovative and such issue may require confidentiality. Anyway limitations, stagnating the technology at a secondary level by significance, are considered further in the analysis.

While companies weren't demonstrating any strategic intentions regarding 3DP, there was an exception – head of marketing and innovations of Company F surely claimed that his company considers 3DP as one of top-3 strategic priorities. What is interesting, this company represents the industry of third-party logistics (further referred as 3PL) providers. This fact is especially important in context of this thesis because despite analyzing companies from wide range of industries, fundamentally thesis is devoted to examining role of 3DP for logistics and SCM practices. Companies representing different industries were intentionally included into this study because the area of logistics and SCM is important for any company even though represents only supporting capabilities. In opposite, for Company F, logistics is a primary field and core capability. Indeed, Company F emphasized the strong potential of 3DP to change dramatically the business model in its industry. Thus admitting the criticality of 3DP role in a greater extent than others, this company gave us a reason to consider 3DP an important lever for driving the development of the industry of logistics services.

Moreover, while investigated firms barely admitted the strategic meaning of 3DP, experts representing 3DP distributors and consulting firm investigating the market of 3DP, expressed

totally different opinion. They surely demonstrated the confidence that 3DP will gain the strength and become a strategically important tool. They also claimed the necessity to educate clients about potential opportunities which 3DP may deliver.

3.3. Cross-case analysis

In this part the information gathered from both primary and secondary sources is collected and systematized. To be clear and illustrative, results of case study are presented consistently according to the issues asked in research questions in the tables below.

Let's recall the research questions:

RQ1: What is the direction of the changes brought by 3DP to SCM practices?

RQ2: Why the changes may become critical for shifting logistics and SCM practices?

RQ3: What are the most probable scenarios of development 3DP in context of SCM practices for the nearest 5-10 years?

The first research question aims at revealing the effects which companies experience from 3DP implementation. Mostly experts are talking about operational benefits which 3DP brings. Representatives of two biggest companies participated in this case study – Ahlers and Technodinamika demonstrated the strategic understanding of the role of 3DP for their companies. Table 3.1 summarized the insights gained from experts regarding the directions of effect derived from 3DP implementation.

Table 3.1. Major insights on the effects of 3DP gathered from the interviews

THE EFFECTS OF 3D printing
INDUSTRY EXPERTS
Venera, co-founder
Started to apply technology 1 year ago; 3DP is used for producing prototypes of jewels; 3DP allowed to: - customize the items - flexible respond to customers' requests - lessen the supply chain because of redundant need to employ third-party jewelers for making a prototype - reduce the final price significantly due to drastic cut in production costs
Massa-K, CEO and founder

Only operational role : - detecting the product defects before launching mass-production - cost reduction due to no need to buy press-forms (from $10,000 to $100)
Ahlers, Head of marketing and innovations
3DP application is in preparatory stage; expected advantages: - stock maintenance costs reduction - decrease in number of losses when transporting
Technodinamika, Head of design and construction center
Practice 3DP in prototyping, potentially consider 3DP for producing end parts and products - strong reduction in energy- and labor-consumption - new product development process becomes significantly more resource-intensive
Petrotech, CEO
Considered the opportunity to apply 3DP but decided that it's not reasonable because of the core direction of business: mass production of details and spare parts
OKB-1, CEO
- no necessity to hire high-paid construction engineers - production cycle reduction
3DP EXPERTS
3DVision, Head of 3D services department
Clients of 3dvision are mostly industrial and engineering companies for which advantages of 3DP are pretty the same: - quick construction of bodyframe - ability to test the batch and detect defects before launching mass production
RUBOT, General director
Clients are mostly companies from consumer industries; - reduced manufacturing price - cut in manufacturing lead times - possibility of single piece production
Cyberon, manager, 3DP expert
Big range of effects depending on the purposes of implementation and underlying characteristics of companies
RESEARCH EXPERT

Group of companies «Training Institute - ARB Pro», consultant, author of 3DP market research
Big range of effects depending on the purposes of implementation and underlying characteristics of companies
ACADEMIC EXPERT
Samara State Aerospace University, head of additive technologies department
Creation of gas-turbine engine and burner can for companies operating in aerospace construction industry; - drastic cut in manufacturing lead time (for burner can 3-6 months before, 2 weeks with 3DP) - avoidance of huge labor contribution required for normal engines production - ability to test and detect defects

The second research question tries to reveal what is needed for changes brought by 3DP to become critical for company. The main point here is company's understanding of the potential which is hidden behind 3DP. Often this understanding exists only at operational level. Firms experience cost and lead times reduction, opportunity to develop product design jointly with consumer and decrease in the number of defective products. The strategic role of 3DP which is about shifting SCM practices due to ability to produce immediately at the point of use, is limited by various circumstances. Table 3.2 summarized the circumstances which companies called main limiting factors for 3DP dissemination and for become a strategic tool.

Table 3.2. Major insights on the limitations of 3DP preventing it to become critical tool of changes

LIMITATIONS
INDUSTRY EXPERTS
Venera, co-founder
Quality issues
Massa-K, CEO and founder

Quality issues: - properties of details printed doesn't allow company to use 3DP for printing the final product
Ahlers, Head of marketing and innovations
- limited range of printed materials - impossible to use for mass-production - low speed of printing - cost of equipment maintenance - property rights issues of CAD models - there are no potential customers for this service (providing digital logistics) in Russia
Technodinamika, Head of design and construction center
- slight resistance from top-management
Petrotech, CEO
- low speed of printing - excessive initial investments - the quality of final printed product, particularly, the visibility of layer structure
OKB-1, CEO
- expensiveness of 3D printers with better characteristics; - focus only on operational role of 3DP which is delivered by simple models of printers
3DP EXPERTS
3DVision, Head of 3D services department
- hardly available and expensive raw materials don't allow 3DP industrial use to move from mostly prototyping to mostly printing end products
RUBOT, General director
- Intellectual property rights for CAD models when it comes to ability to customize the design - Peculiarities of layer-by-layer construction - Lack of informational infrastructure and knowledge about the methods of applying 3DP leads to rather low interest (especially relevant for Russia)
Cyberon, manager, 3DP expert
- low awareness of 3DP technology among potential customers especially in Russia
RESEARCH EXPERT

Group of companies «Training Institute - ARB Pro», consultant, author of 3DP market research
- price for metal powder - speed of printing
ACADEMIC EXPERT
Samara State Aerospace University, head of additive technologies department
- presence of only limited amount of suppliers of material required to print the parts themselves not just prototypes (powder metal in that case) - for any aerospace engines/details etc. certification is needed - long process of testing should be performed to get the abovementioned certification

Careful consideration of both advantages of 3DP and constraints limiting it from further penetration is organically balanced by considering experts' predictions on the future of 3DP development in business context. Experts with one voice agree that 3D printing technology has a potential to disrupt SCM practices in the nearest decade however it will fully depend on the ability to find solutions of the problems defined. These problems include the range, availability and price of raw materials for printing; speed of printing and quality properties of product printed. Some experts also point out the importance of educational aspect and necessity to nurture the understanding of innovative technologies' role at top-managers level, especially in Russian market. Table 3.3 summarizes the forecasts gained from firms' representatives.

Table 3.3 Major insights on the forecast of 3DP development in context of impacting logistics and SCM practices

FUTURE SCENARIOS OF 3DP DEVELOPEMENT
INDUSTRY EXPERTS
Venera, co-founder
In context of jewelry industry technology is already applied by big players and is going to be applied further. The role of 3DP will become more important when not only polymeric prototypes but the jewels themselves will be printed from materials. Currently it is not widespread due to price and difficulty to obtain specific materials for 3D printer
Massa-K, CEO and founder
Doesn't view 3DP as a potential technology to replace current production and disrupt supply chain
Ahlers, Head of marketing and innovations

Assess the technology as having great potential for shifting from physical supply chain flow towards digital supply chain; However hard to predict time horizon of the plans to come true
Technodinamika, Head of design and construction center
Companies' role will change from being a consumer of materials to becoming a consumer of information
Petrotech, CEO
3DP has a potential when applied for expensive goods with the short payback period
OKB-1, CEO
Technology is promising but they don't plan to use it by any other means except for printing some spare parts; Generally they don't view it as a revolutionizing tool; 3DP hides a huge potential for military-industrial sector
3DP EXPERTS
3DVision, Head of 3D services department
3DP will gain especial relevance for military-industrial complex, medical industry and mechanical engineering
RUBOT, General director
Intellectual property is a big deal. The world started mass printing of prototypes only a few years ago when patent for this technology of 3D Systems expired. For technology to become used at a mass level and to change current SCM practices, printing with different materials should become more widespread. Currently it is constrained with the price of materials, the inaccessibility of these materials . Moreover, in order to payback the products printed via 3DP should be of a huge batch; So far abovementioned constraints doesn't seem to be avoidable in the nearest 5 years
Cyberon, manager, 3DP expert
Educational programs are needed in order to rise awareness and increase the commercial interest to 3DP from potential B2B consumers
RESEARCH EXPERT
Group of companies «Training Institute - ARB Pro», consultant, author of 3DP market research
3DP has a huge potential to revolutionize supply chain and when two major latching factors are overcome; By 2023

- the price for printing with metal powder will drop by 3 times - the speed of printing will rise by 7 times
ACADEMIC EXPERT
Samara State Aerospace University, head of additive technologies department
So far technology is very innovative and it seems like we are too far from 3DP bringing any dramatic changes to SCM practices due to the reasons mentioned in previous colomn. Doubtful that technology will become mass-used within 5-10 years. It is too early to speak about the eliminating of logistics and SCM as a discipline. Anyways suppliers will be needed for providing raw materials.

To sum up, experts participated in the interviews interestingly were talking about approximately the same directions of effects of implementing 3D printing independently from the industry. However what was noticed is that firms operating in industrial sector make stronger emphasis on some of the effects, whereas firms from consumer goods sector – on others. The same is true about the perceived role, value and potential of 3DP technologies for firms' SCM practices. For instance, companies from industrial sector seemed to assess the role of 3DP as a more strategic than companies from the sector of consumer goods. Also representatives of smaller firms made more emphasis on short-term results gained from 3DP implementation, whereas bigger firms demonstrated more reliance on its long-term role. Thus based on this observation, the insights gathered from interviews to be tested by means of survey are the following:

- companies operating in both industrial and consumer sectors are leveraging from 3DP implementation

- both groups of companies are able to cut production costs as well as manufacture lead times

- for industrial companies one of the most important effects is ability to test the construction of detail/product before launching the mass production

- 3DP has a potential to become mass-used in companies operating in industrial and engineering more probably than in companies from consumer sector

3.2. Post-hoc analysis

In order to support or deny the results obtained in the basic part of empirical research, the survey was comprised and spread among companies applying 3DP via corporate newsletters organized by 3DP sellers and distributors. Eventually 28 answers were collected. The survey was filled by 16 companies representing industrial sector (aero construction, glass industry, engineering, industrial equipment, etc.) and by 12 firms representing consumer goods industry (souvenirs, home staff, jewelry, food, dentistry, decorative mockups, etc.).

We noticed that reported results were quite different for firms from industrial and consumer goods sectors. That is why the findings of survey are presented below split by sector.

Figure 3.2 Average time of 3DP implementation in companies

From Figure 3.2 we observe that firms from industrial sector on average employ 3DP longer than those operating in consumer goods. Other findings are basically corresponding with this one.

When analyzing the most important effects which 3DP brings to companies, we again split it depending on the industry (Appendix 2). Effects are different for two groups of companies. While consumer goods firms emphasize the possibility to customize products, industries' representatives claim that reducing the number of suppliers and steps in production and construction processes are key advantages.

The results described above gave as a reason to consider that companies operating in industrial sector tend to assess the role of 3DP as more critical and important than firms operating at consumer goods (Appendix 3a, 3b). We tested this assumption by means of statistical tool – t-test which shows the equality of means or denies it.

H1: companies operating in industrial and consumer goods sectors tend to assess the role of 3DP as equally important

Table 3.2 Results of t-test applied to H1

Sector	Consumer	Industrial
n	12	16
mean	2,1	3,2
t-statistics	0,04	

The significance of p-value of t-statistics at 0,05 level of significance make us to deny the null hypotheses and claim that difference in assessing the role of 3DP between industrial and consumer goods' firms exists. The former tend to perceive 3DP as a **more critical** for their primary activity.

The following hypotheses are also aimed at revealing the differences between 3DP impact on different industries.

H2: companies operating in consumer goods sector tend to have bigger cost savings than those operating in industrial sector

Table 3.2 Results of t-test applied to H2

Sector	Consumer	Industrial
n	12	16
mean	45	22,86
t-statistics	0,09	

At 90 % confidence level it can be claimed that companies operating in industrial and consumer sectors have different reduction in production costs due to 3DP implementation. Moreover, firms from consumer sector tend to have higher cost savings.

H3: companies operating in consumer goods sector tend to have bigger reduction in manufacturing lead times than those operating in industrial sector

Table 3.3. Results of t-test applied to H3

Sector	Consumer	Industrial
n	12	10
mean	79,2	67,00
t-statistics	0,62	

It can be stated that companies operating in both industrial and consumer sectors have approximately the same decrease in leas times due to 3DP implementation because the difference was proved to be statistically insignificant.

Generally, the results gained by means of survey supports the insights gained at the first phase of empirical research.

Discussion and findings

Extensive and thoughtful examination of the role of 3DP in context of logistics and SCM has demonstrated that topic is deservedly among the key trends impacting global logistics and SCM area. Analysis of academic articles, industry reports and latest news has shown that implementation of 3DP is a hotly debated topic which is believed to bring radical consequences to different areas including logistics and supply chain management. Experts from different companies proved that implementation of 3DP has led to improvements. All of them agreed that 3DP caused reduction of production costs and manufacturing lead times.

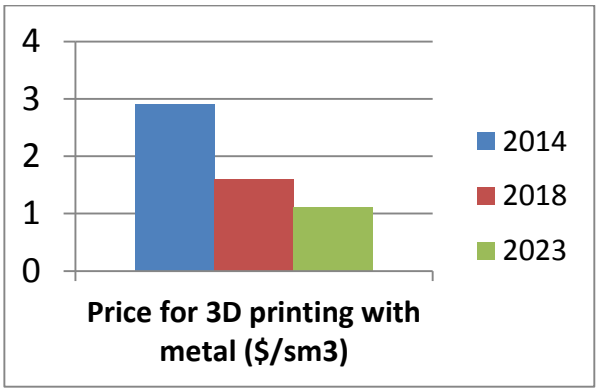
Considering primary goal of the research, it can be stated that 3DP implementation impacts significantly companies logistics and SCM strategies. These effects are quite various however fundamentally they may be split into two large categories: increase in supply chain responsiveness and optimization of SCM costs. Both of the categories relate to key indicators of supply chain performance. So we can argue that effect of 3DP implementation is substantial enough due to its pervasive impact on different areas of logistics and supply chain management.

Extensive empirical research which included a dozen of interviews and filling the survey helped to construct scenarios of 3DP future development in context of logistics and SCM. Despite the fact that technology has a huge potential and is expected to become one of the most disruptive innovations for logistics and SCM area, experts are quite unsure about the time horizon for these expectations to become true. Current limitations constraining 3DP from mass dissemination are very significant and it is hard to forecast when they will be avoided. The lack and expensiveness of materials used for printing, intellectual property rights for CAD models, speed of printing,

equipment maintenance are named among the critical factors stopping 3DP from becoming a primary production tool. Among the interviewees, only one company has demonstrated strategic intentions towards 3DP and readiness to make capital expenditures in the nearest time. This company is 3PL provider which sees the role of 3DP as radical for their business – a basement for shifting from physical supply chains towards digital ones.

Although today in Russia very few companies demonstrate readiness to embrace this potential, we believe that at a horizon of 5-10 years much more firms will use 3DP strategically – for printing end products at the point of consumption. This shift towards mass implementation of 3DP for producing end products will be caused by diminishing two main constraints: availability and expensiveness of raw materials for printing and speed of printing. Among possible range of raw materials used for printing, metal is the most important one in strategic sense. The aggregated forecast comprised by Siemens and ARB Pro consulting agency claims that price for 3D printing with metal will drop 3 times by 2023 (figure 4.1).

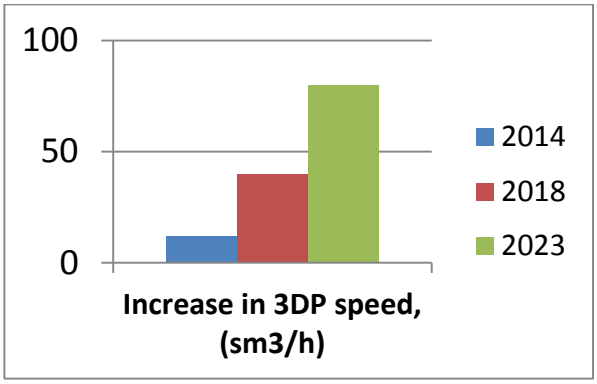
Figure 4.1 Forecast of price for 3DP with metal



Source: Siemens and ARB Pro

At the same time technology's improvements will drive the speed of printing up to 8 times by 2023 (figure 4.2). Simultaneously with price reduction and speed increase the penetration of 3DP in business environment will rise.

Figure 4.2 Forecast of speed of 3D printing



Source: Siemens and ARB Pro

We believe that such improvements will incur significant increase in the number of companies applying 3DP as well as shift in the attitude of firms towards 3DP from operational to strategic.

Theoretical contribution

When investigated the consequences of 3DP implementation, we found out that they are sometimes out of synch with SCM concepts. Since there is no scientific theory underlying the 3DP technology in context of logistics and supply chain management, we thought it is interesting to see where traditional SCM concepts don't tie in with 3DP implementation.

The basic conceptual definition of SCM traditionally includes material flow of goods (Lummus and Alber, 1997; Cooper 1993). Logistics as an essential part of SCM encompasses the process of physically moving the goods between different points. To organize relevant physical movements of the products is traditionally primary task of logistics. In the long-term prospective, 3DP implementation in the field of logistics and SCM will diminish the meaning of physical flow of goods and replace it with digital flow. This discrepancy demonstrates that 3DP technologies may disrupt the theoretical foundation of logistics and SCM as disciplines.

The concept of measuring SC performance is also getting disrupted by 3DP. Depending on the functional activity within SC there are different key performance indicators. However they may be aggregated into bigger groups which are costs and responsiveness (Ginasekaran, Patel, 2004). It is traditionally considered that ideal supply chain should strive to minimize total costs and to maximize responsiveness. Mass implementation of 3D printing makes supply chain ideally

responsive because of the ability to print spare parts and end products according to the customer request and do it at a point of use. This challenges traditional supply chain performance concepts to elaborate new KPIs.

Besides, 3DP mass implementation In the earliest concepts different parts of SC often opposed each other what caused delays and other problematic situations. That was one of the reasons why integration in SC became such a popular concept. Afterwards it was realized that integration is more valuable in terms of SC effectiveness. In essence introduction of 3D printing makes some participants of supply chain redundant thus eliminating the necessity to integrate. By employing 3DP organization becomes able to concentrate all the value adding activities. This contradicts to the concept of supply chain integration. No one research investigated to what extent introduction of 3DP is consistent with contemporary SCM concepts.

Managerial implications

The findings of current research indicate that 3DP truly has a potential to revolutionize traditional practices in logistics and SCM. Since this may have an impact on the some industries as well as on particular business trends which are relevant today, we split managerial implications into two groups: relevant at the industry-level and at the firm-level.

Global level

Looking at a global scale 3DP will impact global manufacturing schemes. One of the most important consequences of mass 3DP implementation is **facilitation of reshoring**. Reshoring is a practice of bringing manufacturing facilities from low-cost countries back to the countries of origin. The term "reshoring" first emerged in 2014. The reasons which encompass sound comprehension of why phenomena is happening include reduction in outsourcing, transportation and coordination costs; flexibility for responding variable needs of consumers; currency exchange issues' elimination; cash-to-cash conversion cycle reduction and many others (Fratocchi, Ancarani, 2016). The opportunities offered by 3D printing also serve as a strong driver facilitating reshoring process. Because 3D printers enable local production, the cost advantages of developing countries may be diminished in the long run (C. Weller et al., 2015). Fully automated manufacturing at the point of use makes manual labor force redundant

what makes the main advantage of low-cost manufacturing countries irrelevant. We do believe that further dissemination of 3DP technology will drive reshoring process.

We consider this consequence as particularly important because it regards changing global manufacturing trends and schemes.

Industry-level

Speaking about logistics and SCM as an industry, there are some important consequences which will shape industry development in the following decades.

First of all, **redistribution of the roles of functional activities** within SCM field will happen. Planning stage will become less important than it is now due to high responsiveness offered by 3DP. Sourcing will still be important since raw materials for printing are always needed. However we believe that sourcing will be less complicated and less strategic than it is considered today since the pool of suppliers and their significance will be reduced. The role of transportation logistics in context of supplying spare parts will expectedly decrease. However what regards transportation in delivery of final products, 3DP barely will have any effects here.

Another important effect tightly connected with the first one is **shift of core competencies in logistics and SCM**. Since 3DP allows supply chain to be ideally responsive, one of main performance indicators of SCM may be diminished in the long run. Responsiveness will no longer be the measure of excellent supply chain since core competences will move to digital field. Particularly, companies which have an expertise in creating CAD models and securing them in terms of intellectual property rights, will possess competitive advantage.

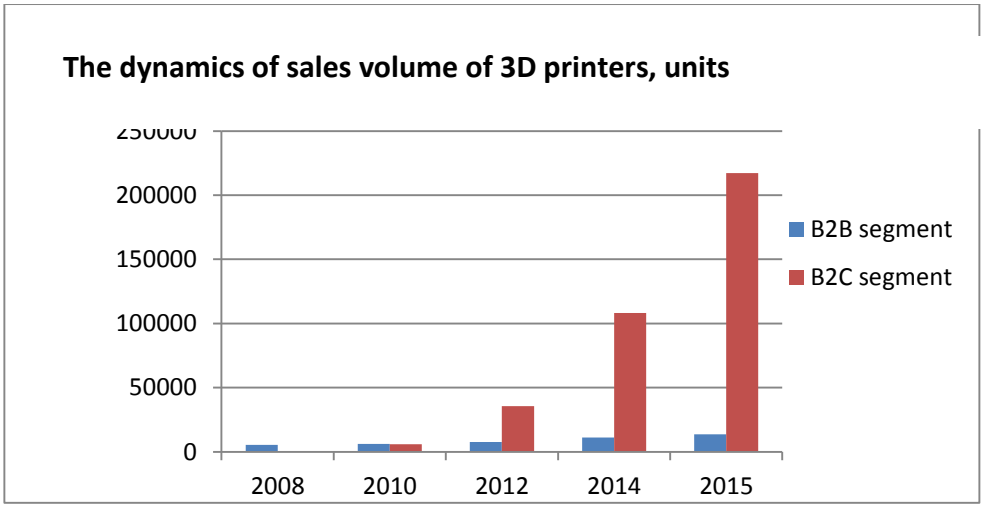
3DP is also expected to cause **disaggregation of global supply chains**. Complicated coordination of various parties in supply chains of multinational corporations is expected to decline in significance since the number of players in supply chain will be reduced. Particularly, 3D printing will make some groups of suppliers unnecessary and in general facilitate direct dialog between company and consumer.

One more important consequence of 3DP ubiquitous adoption refers specifically to the industry of 3PL providers: **shifting physical flow supply chain towards digital one**. 3D printing represents the threat for 3PL providers because it allows companies to get rid of the necessity to use their services. Nevertheless 3DP is often viewed as an opportunity for 3PL to innovate. As mentioned before, 3DP contributes to integration of SCM and IT. 3PL providers view this opportunity as a way to change business model dramatically by acquiring new competitive advantage. This advantage is operating totally digital supply chain. By acting so

3PL providers will not only preserve their marketplace but also acquire innovative competencies which will maintain their business thriving.

Eventually, B2C **3D printing allows end consumer to create its own supply chain and become its owner**. Indeed, the growth rate of 3D printers' use in B2C segment exceeds dramatically the one in B2B segment. It is expressed in increase of the sales volume of home printers which was growing faster in recent years than of professional ones. The volume of home printers sold in absolute values significantly exceeds sales of professional ones (table 4.1). Thus we believe that consumers possess an opportunity to organize their own "small factory" at home creating a new supply chain – 3DP seller and raw materials seller + end consumer. End consumers becoming the main member in supply chain represents radical shift of roles in traditional supply chain.

Table 4.1 Sales of professional and home 3D printers



Source: ARB Pro Training Institute

Firm-level

To formulate sound managerial implications for single firm's managers, insights gained from case study and post-hoc survey analysis are used.

Current investigation revealed that only in Russian market there are quite a lot of companies dealing with 3DP. The majority of them use the technology in order to enhance

operational capabilities, others strive to make their supply chains more responsive and flexible. The survey answered by 28 firms has demonstrated that all the firms gained benefits of production costs reduction and decrease in manufacturing lead times due to 3DP implementation. However statistical analysis has demonstrated that companies incur different extent of abovementioned improvements depending on various characteristics. Size of the firm, industry, time of applying 3DP is among these characteristics. For instance, **medium and large companies generally tend to experience bigger reduction in production costs due to implementation of 3DP comparing to small ones**.

During the empirical stage we also revealed that some particular characteristics of the company are key for 3DP being particularly economically viable and advantageous. Particularly, for companies which operate with high demand volumes, exploiting the benefits of 3DP is problematic. **Firms dealing with low and medium demand volumes have a potential to use the benefits of 3DP to a greater extent**.

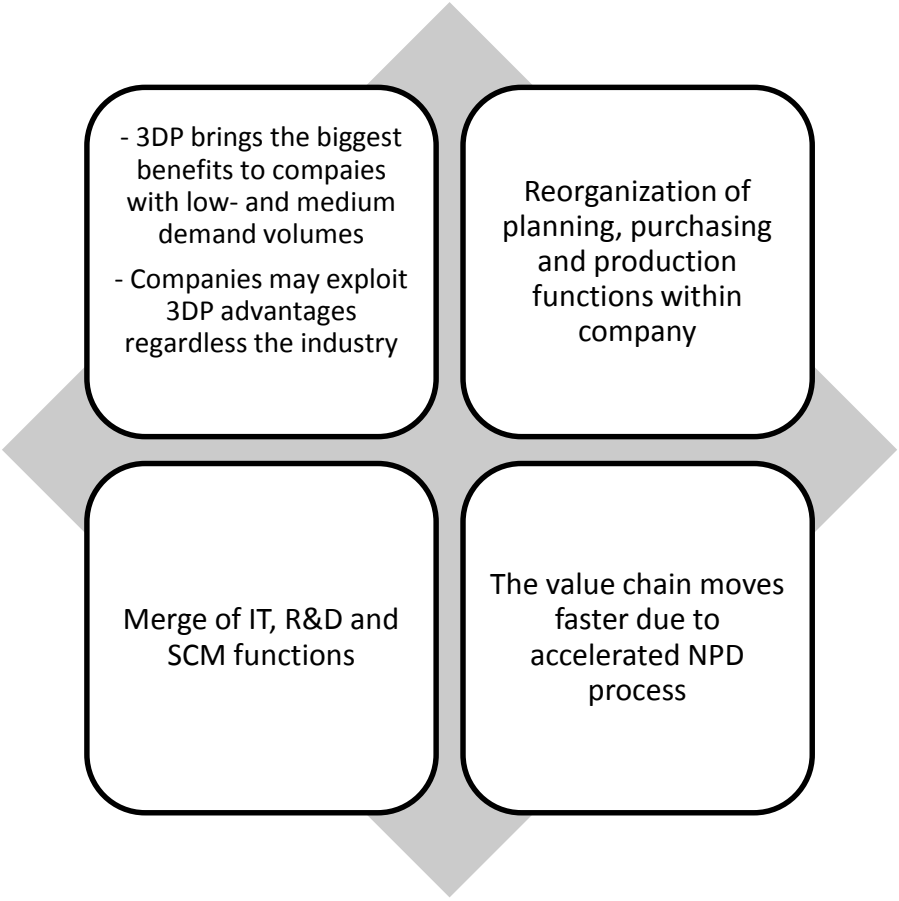
Besides it was revealed that **companies may exploit the potential of 3DP regardless the industry** in which they operate. Case study analysis encompassing the stories of firms from both consumer goods and industrial markets showed that both may beneficially apply 3DP.

Another group of managerial implications regards SCM function within organization. We believe that firms will experience **reorganization of planning, purchasing and production functions within company** due to 3DP adoption. This reorganization is going to be caused by switching the significance of activities and changing the role of some jobs. Specifically, the integration of IT into SCM will create the demand for specialists with both solid IT expertise and understanding of SCM. **S**taff at purchasing department may be reduced because of elimination of some suppliers. At the same time the role of customer service within SCM is going to rise because 3DP adoption drives new level of customer relationship management promoting more flexible and direct communications.

Moreover, since new SCM competencies will be connected with ability to create and secure solid CAD model given specific product's properties, **IT, R&D and SCM functions will merge** to some extent. Rising necessity to come up with CAD models of parts and products encompassing specific characteristics speeds up and advances new product development (NPD) process within organization. In its turn, NPD accelerates all the intercompany processes thus **3DP implementation makes the value chain to move faster**.

Implications of 3DP adoption at a firm-level are summarized in figure 4.3. We would underline that such a consequences will be especially relevant and observable only when 3DP will become significantly wider used than it is now, especially in Russia.

Figure 4.3 Implications of 3DP adoption at a firm-level



Limitations and directions for further research

The biggest limitation of this thesis is impossibility to complement it with comparative analysis of firms' exact figures and performance indicators which potentially could be impacted by 3DP adoption. Due to the innovative nature of phenomena investigated in this paper, companies were either reluctant to disclose the details about 3DP implementation or constrained by confidentiality agreement. This is especially true for companies operating in industrial and construction sectors because for them significant impact of 3DP is connected with R&D and characteristics of new product development which are usually under confidentiality.

Since this research is concerned about 3DP in context of supply chain management, B2B market was in the spotlight of this paper. As shown in managerial implications, the branch of 3DP which regards B2C is going to develop actively in the following years. Since 3D printing for enterprises is confidently moving towards achieving the maturity stage, large uncovered potential lies in B2C segment which is only passing the stage of disillusionment (Gartner

Technology Hype Cycle). Thus we believe that 3D printing in B2C segment is a worthy topic for further research.

Besides, this paper used multiple case study analysis to gain extensive data from various companies. It didn't give us opportunity to examine in details each particular industry which is under 3DP impact. So investigating the potential of definite industries in context of 3DP implementation represents an interesting direction for further research.

Conclusions

In current research 3D printing technology was investigated in context of impacting global logistics and supply chain management practices. Extensive research included evidences from real companies implementing 3DP. Face-to-face interviews with these firms' representatives and careful examination of relevant documentation helped to uncover important insight and answer stated research questions.

We revealed that companies implementing 3DP experience approximately the same range of effects brought by technology. They include mostly operational advantages: production and transportation costs reduction, detecting the product defects before launching mass production, reduction in energy- and labor-consumption. However some companies emphasized other effects related to firm's activity at strategic level and facilitating change of business model: opportunity to customize items leads to change of relationships with customers; lessening the complexity of supply chains leads to elimination of the whole groups of suppliers; switching focus to new core competencies leads to merge of new product development, IT and SCM functions.

The majority of companies participated in case study didn't demonstrate the intentions to switch the way they use 3DP to a more strategic. However two firms – 3PL provider and avia construction holding view 3DP as a highly promising technology and plan to implement it at strategic level. Namely, 3PL provider considers shifting physical flow of goods towards digital one but avia construction holding plans to produce end parts not just prototypes by means of 3DP.

At the same time almost all the experts participated in this research expressed confidence that 3DP will further develop and disseminate in business environment in the nearest decade. Breakthrough driving mass implementation and persuading companies that 3DP has a potential

to change current logistics and SCM practices is constrained by a number of limitations. The most serious of them include unavailability and expensiveness of materials for printing, some particular characteristic of 3D printers and people's conservative mind. Estimations made by Siemens and ARB Pro showed that by 2023 these constraints are expected to be successfully solved. It gives us a reason to believe in great potential of technology for bringing new ways of managing logistics and supply chains.

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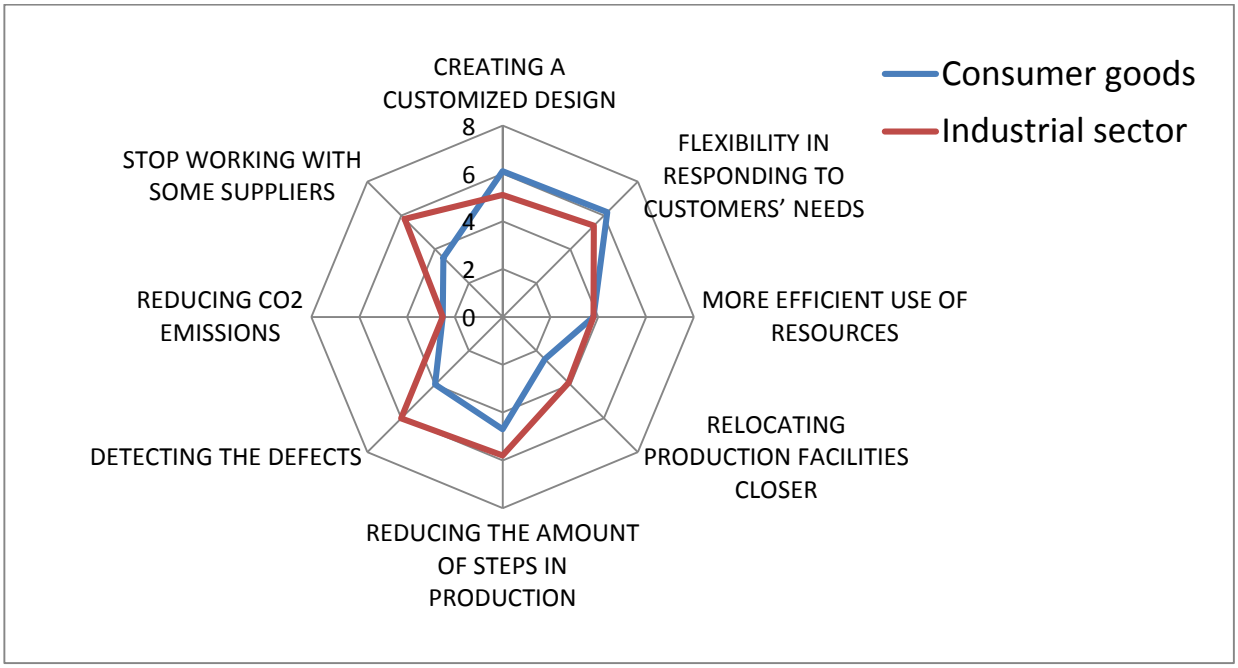
Appendices

Appendix 1. Survey script

Part 1. Introductory questions								
1	In which industry your company is operating?							
2	What is your position?							
3	What is number of employees in your firm?	< 15…..……..…….. 15-99…….. 100-250…….. > 250…….....					1 2 3 4	
Part 2. Experience with 3DP implementation								
4	For how long your company have been applying 3D printing technologies?	< 3 months……..……..... 3-6 months..... 6 months-1 year..... 1-2 years…….. > 2 years…….....					1 2 3 5	4
5	How (at which stage) your company is applying 3D printing?							
6	Please mark what are the main advantages for you company from applying 3D printing technologies and to what extent (where 1 – this effect is irrelevant for my company; 7 – relevant for my company in a great extent)	1	2	3	4	5	6	7

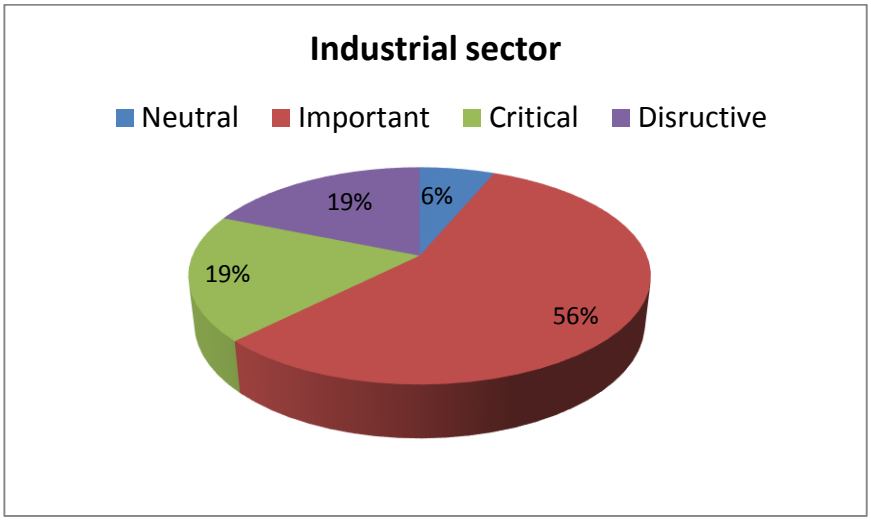
	CREATING A CUSTOMIZED PRODUCT DESIGN CONSIDERING SPECIFIC CUSTOMERS' REQUESTS							
	FLEXIBILITY IN RESPONDING TO CUSTOMERS' NEEDS IN TERMS OF TIME, DESIGN ETC.							
	MORE EFFICIENT USE OF RESOURCES							
	ABILITY TO RELOCATE REMOTE PRODUCTION FACILITIES CLOSER							
	REDUCING THE AMOUNT OF STEPS IN PRODUCTION/ASSEMBLY PROCESS							
	TESTING AND DETECTING THE DEFECTS OF BATCH BEFORE LAUNCHING THE MASS PRODUCTION							
	REDUCING THE CO2 EMISSIONS DUE TO OPTIMIZATION OF TRANSPORTATION FLOWS							
	OPPORTUNITY TO STOP WORKING WITH PARTICULAR SUPPLIER OR GROUP OF SUPPLIERS							
7.	PLEASE, MARK TO WHAT EXTENT 3DP IMPACTS THE FOLLOWING INDICATORS							
	REDUCING MANUFACTURING LEAD TIME	BY 10-30 %	BY 30-50 %	> 50 %	> 100 %	DIDN'T IMPACT		
	REDUCING COSTS OF PRODUCTION PER ITEM (INCLUDING PRODUCTION COSTS, COSTS OF MATERIALS, DELIVERY COSTS)	BY 10-30 %	BY 30-50 %	> 50 %	> 100 %	DIDN'T IMPACT		
PART 3. PERSONAL IMPRESSION								
8.	HOW WOULD YOU DESCRIBE IN ONE WORD THE ROLE OF 3DP TECHNOLOGIES FOR YOUR COMPANY?	Very impotant……..……..... Important..... Neither important nor unimportant..... Unimportant……..... Very unimportant……..... 1 2 3 4 5						
9.	WHAT ARE THE PERSPECTIVES OF 3DP DEVELOPMENT IN CONTEXT OF YOUR INDUSTRY?							
10.	WHAT ARE THE DEVELOPMENT SCENARIOS OF 3DP TECHNOLOGY IN CONTEXT OF LOGISTICS AND SUPPLY CHAIN MANAGEMENT PRACTICES FOR THE NEXT 5-10 YEARS?							

Appendix 2. Effect from 3DP implementation for firms operating in consumer goods and industrial sectors



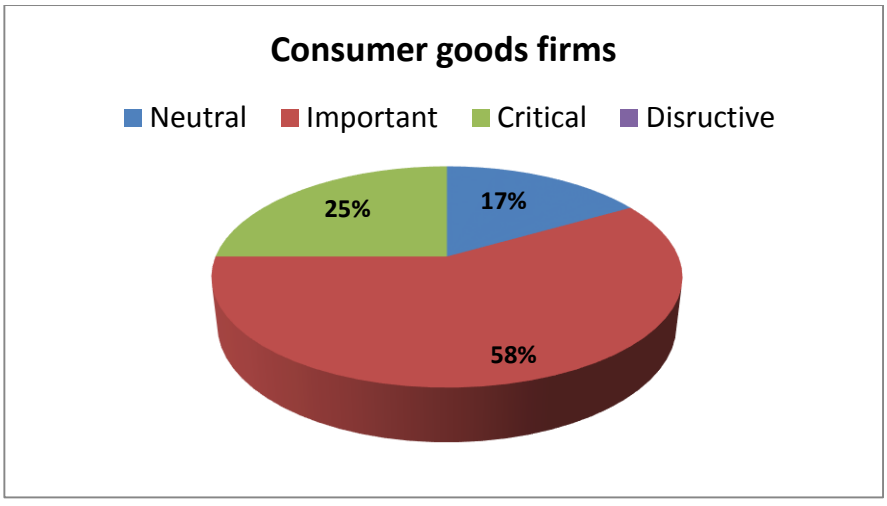
Source: author's survey

Appendix 3a. The assessment of the role of 3DP for your companies from industrial sector



Source: author's survey

Appendix 3b. The assessment of the role of 3DP for your companies from consumer goods sector



Source: author's survey