The impact of digital evolution on Mass Customization towards industry 4.0: a new transition for supply chains in manufacturing industries

Enrico Fiorentin - *PhD, Università degli Studi di Padova* - fiorentin@gest.unipd.it

Alberto Maria De Crescenzo - *PhD, Università degli Studi di Padova* - albertomaria.decrescenzo@phd.unipd.it

Andrea Vinelli - *Full Professor, Università degli Studi di Padova* - andrea.vinelli@unipd.it

Irene Marchiori - *Researcher, Consiglio Nazionale delle Ricerche di Milano* - irene.marchiori@itia.cnr.it

Rosanna Fornasiero - *Researcher, Consiglio Nazionale delle Ricerche di Milano* - rosanna.fornasiero@itia.cnr.it

Keywords: mass customization, industry 4.0, supply chain

Topic: Supply Chain Management in Manufacturing

Summary abstract

Companies that manage to adopt a successful strategy in the customization field get a double benefit: they increase customers' willingness to pay more and they manage to make the same customers purchase more products of the same brand. Here are presented the main impacts (positive and negative) at different levels that could come as result of its implementation. Our study brings some hints to answer some recent open questions about the need of matching the theory bases on supply chain evolution among operations management, supply chain management, and procurement areas (MacCarthy, Bart L. et al., 2016).

Introduction

Companies that manage to adopt a successful strategy in the customization field get a double benefit: they increase customers' willingness to pay more and they manage to make the same customers purchase more products of the same brand. These customers feel involved and coddled, much more than a customer that buys standard products. At the same time, customization is not only about customers: the vendors are also working to increase both products variety and sales channels.

Scientific literature on mass customization (MC) has produced several studies on the platform concept and the technologies that support it. Conceptualizing appropriate platforms can help creating each customized smart product, which can serve as a platform for personalized smart services with the help of smart data; the importance of each technology in supporting different sectors is well known, but there are no systematic approaches to contextualize innovation towards industry 4.0, tying it to management and strategic innovation (Camarinha-Matos, Luis M. et al., 2017). Knowledge of digital technologies is now open source on many levels, but no connection has ever been established between adopting MC-enabling technologies, company-wide strategies and supply chain implications.

We describe the four archetypes, based on the mapping of recent trends affecting business, and analyzed each of them in the real industrial context. Then we outline a customized mass production

scheme that represents the supply chain of the future for the process/manufacturing industries. Companies who have decided to include MC among their development strategies will have different impacts in a large variety of topics, such as customized production, materials management, waste reduction, etc. Therefore, here are presented the main impacts (positive and negative) at different levels that could come as result of its implementation. Our study brings some hints to answer some recent open questions about the need of matching the theory bases on supply chain evolution among operations management, supply chain management, and procurement areas (MacCarthy, Bart L. et al., 2016).

Methodology

Concerning our studies, one of the major motivations of the INSPIRE[1] project is to develop mechanisms and solutions to make European process industry more competitive and relocalize high-value added activities in the medium term. In particular, this work aims at redesigning the supply chain. We adopt the multiple case studies method by applying a structured interview protocol that fit with the objective of conducting qualitative research in this field. The selected companies are based in Italy, they are leaders in their market and have a structured organization (establishment >5 years), and they are large sized (>250 employees and >50 million revenues).

The three business cases respectively are leaders in the footwear, leather, and steel sector; they have an international market to compare different solutions and possibly achieve economies of scale and scope. To provide a solution to the presented issue and the need for a fast adaptation from the companies and industries, the main results have been presented based not only on interviews with companies, but also on literature review, comparison with other academicians, and different industry reports, which were analysed by three people working on this project.

We describe the case studies and the tools that companies used to customize their processes and the supply chain they are part of. Once we have analyzed the relevant directions each sector chose, we describe the empirical evidence with the use of data and graphical aids. In order to develop innovative business models for European process industry, we present the results of our research on the major technologies, business models and challenges of industry 4.0 implementation.

Mass customization and Industry 4.0

MC combines the personalization and flexibility of custom-made business manufacturing with the traditional principles of mass production. It consist of a combination of mass production (large batching production) with the elements of tailoring products in a way they meet each customer individual needs. The advantage of MC is the usage of mass production techniques (e.g. small number of platforms that underlie different product) to create individual products. The product customization could be also considered like a social trend for which the customers want tailor-made solutions in order to fit their own personality. Society can no longer be divided into homogeneous target groups, but increasingly consists of many different niche groups (Pedz, 2009) and the companies have to face this trend. According with Deloitte, 36% of customers are interested in personalization and 22% are happy to share some data in return for a more personalized customer services and products. The price is not a barrier in fact 1 in 5 consumers who expressed an interest in personalized products or services

[1] The INSPIRE project was funded in the frame of Horizon 2020. INSPIRE focuses on developing new innovative business models for more flexible and sustainable manufacturing value chains, and delocalized approaches for intensified processing.

are willing to pay a 20% premium. Holidays (25% of customers), clothing (19%) and furniture (18%) are the three categories that customers make personalized purchases.

The shift towards MC is reinforced by new manufacturing technology trends. Fast increasing rates of investment in advanced robotics, additive manufacturing and advanced digital simulation of manufacturing processes all lend themselves to shorter production runs and more unit-level customization. An increasing number of manufacturing industries and brands are adopting the business concept MC nowadays. According to the Boston Consulting Group, the implementation of the Industry 4.0 will lead to a growth in the German GDP of around 1.1% and allow the creation of about 400 thousand new jobs: this imply an increase in productivity of between 5% and 8% over the next 15 years.

The shift towards Industry 4.0

The theme of Industry 4.0 includes the description, definition and organization of production processes based on technology and devices autonomously communicating with each other along the value chain. In the document entitled Industry 4.0 by European Parliament - Department for Economic and Scientific Policy a definition for this theme is provided (3): Industry 4.0 is a new paradigm for the future *Smart Factory* where Computer-Driven Systems (CDS) monitor and manage physical processes, create a virtual copy of the real world and make decentralized decisions based on self-organization mechanisms. This paradigm takes account of the increased computerization of the manufacturing industries in which physical objects are faultlessly integrated into the information network. As a result, "manufacturing systems are vertically networked with business processes within factories and enterprises and horizontally connected to spatially dispersed value networks that can be managed in real time – from the moment an order is placed right through to outbound logistics" [10]. These developments make the distinction between industry and services even less relevant as the shift to the service factory (Panizzolo R. et al., 2017) is arising where digital technologies are combined with industrial products and services into hybrid products.

Business cases description

Solarium is a company that operates in the high-performance soles industry and currently has a leading position in its market. The Headquarter is located in Lombardia (North Italy), together with one of its manufacturing plants; the company is present in five other locations among USA, China, Japan and Brazil, with over 650 employees (of these 1/3 are in Italy). During the last years, the revenue has always been over €150 million, with the 80-85% coming from the soles sold as shoe components to footwear producers, and 15-20% from the Fivefingers (special shoes assembled by the company itself) and other finished products. The company produces over 40 million pairs of soles and develops over 300 new products each year. The most important applications in the footwear sector are soles for: mountain, snow-sports, work safety, military, lifestyle, outdoor, motorcycling and repair. The sole is an important component of the shoe: also known as the outsole, the sole is the bottom part of the shoe that comes in direct contact with the ground. Shoe soles are made from a variety of different materials, including natural rubber, leather, polyurethane and PVC compounds. The material used to make the sole depends upon the style and purpose of the shoe.

Dominia was born as a small family tannery, and after the fusion between Gruppo Dominia and Dominia Automotive it now has about 1,000 employees and collaborators. The company is based in Veneto (North Italy), the biggest tanning district in the world, and it produces fine Italian quality leather for different markets: automotive, furniture, IT, footwear, and clothing. Dominia tans leather

for the automotive, IT, footwear, and clothing sectors. The Dominia label is synonymous with product sustainability (EPD, carbon footprint), and innovation together with minimization of environmental impact are priorities of the company. The company is environment - and safety -conscious, as well as focused on research aimed at the development of high-quality innovative products. It has managed to be certified as a sustainable enterprise, and was the first in the world in this sector to obtain the Carbon Foot Print Certification.

Morganti operates in the steel sector specialized in selling steel products for different applications to construction companies, car makers, mechanical firms and other sectors, in organizing fairs and events and offering sectoral news and information With its headquarters in Lombardia (North Italy) close to the main supply markets and outlets. Morganti SPA has two distribution facilities in buildings covering 7,000 sq.m. of the 20,000 sq.m. total area. Morganti's plant is part of a bigger group, called Morganti Group, which embrace several companies. This favorable geographical location gives the opportunity to rapidly and efficiently manage the logistics system, also thanks to the support of skilled operators in the road haulage & logistics sectors. Morganti SPA can also rely on well-established relationships and on the trust recognized with the most significant and qualified Italian, European and global steel producers, thanks to which it can manage planned supplied with significant benefits from an economic and logistic viewpoint.

The analysis of these successful case studies highlighted that MC can be strictly and successfully connected with decentralized production, sustainability, and servitization. These business model archetypes are similar to those suggested in Bocken et al. (2014) (i.e., "Maximize material and energy efficiency; Create value from 'waste'; Substitute with renewables and natural processes; Deliver functionality rather than ownership; Adopt a stewardship role; Encourage sufficiency; Re-purpose the business for society/environment; and Develop scale-up solutions"). Before discussing the implications of the in-depth case studies analysis, we describe the main technology classes that support these trends.

Business cases analysis[2]

Solarium's defining trait is flexibility. The marketing department, which works on a global scale, can quickly identify new market opportunities and communicate the news to the whole company. In order to match this speed, the company built new factories very close to new clients; the most striking example was the creation of a new production plant in Brazil in less than a year. Orders are received by the central headquarters, then passed on to contractors depending on the delivery deadlines; contractors handle sole production, but they do not have the development and design capabilities that Solarium has. There is no vertical integration: the company uses several upstream suppliers and sells the finished product to distributors who deal with sales. Solarium performs quality control checks on random samples and controls the process.
The choice to decentralize production is due to the need to keep the products' quality closely monitored. The opportunity to work with local vendors reduces logistics overheads and favors the creation of tight bonds with clients, who provide useful feedback to improve products. The new technology Solarium is investing on the most is the 3D scanner, connected to a 3D motion capture device and shoes design configurators. The medium term objective, which is showing signs of success in pilot lines, is the creation of micro-units of flexible machinery that allow production of small batches of soles very quickly, in order to reduce delivery times.

[2] Companies are cited with made up names due to an agreement with the companies

Dominia tans leather for the automotive, IT, footwear, and clothing sectors. The Dominia label is synonymous with product sustainability (EPD, carbon footprint), and innovation together with minimization of environmental impact are priorities of the company. The focus of the company is on the environmental issues. They are always looking for new trends and collaboration in order to keep and develop the sustainability trends. The company is building a structured approach to research new processes and create new chemical components that will enable to realize more and more "green" products. Now, this is handled in ad hoc research projects in partnership with other companies and suppliers: one of the first key outcome is the zero impact leather.
The oxidative depilation obtained with the use of hydrogen peroxide was introduced in a special polypropylene stick. This technology enables to obtain re-used by-products in the industrial, agro-industrial and energy sectors. This process, at a semi-industrial scale, will completely replace the current production over the next few years. New tin-free metal-based technologies have been developed, based on the use of enzymes and polysaccharides that give the skin the same physical and mechanical characteristics of skins treated with traditional tanning. Also for the recoating and finishing phases are selected ad hoc products, which have a very low metal content, so as not to compromise the results obtained during the tanning phase. Even water-based products have been chosen for the refining phase. The sustainability effort is clear to all the consumers and all this lead to an accurate evaluation and selection of providers and partners, together with an internal continuous effort on proactivity and innovation.

Morganti, which operates in a sector with a slower pace of innovation, is investing strongly on digitalization. Steel is everywhere and can be sensed to collect information that can be used at multiple levels providing a service to different stakeholders (e.g., sensors embedded in bridges can provide data useful data tor steel producers, car manufacturers, infrastructure managers, etc.). Industry 4.0 is about processes: it is not just selling steel through e-commerce. Morganti is aware that marketing, web, storytelling, logistics, sales, and storehouses have to work together to form a coherent whole. The company, for example is willing to implement an automated order-handling platform, integrated with suppliers to handle warehouses efficiently, without making orders constantly, thanks to this real-time communication.
The company promotes important initiatives for the sector such as "Morgantiweb", which is a community of the Italian steel industry including all the main stakeholders of the steel supply chain sector. Morgantiweb web was created to respond to the need for information, service and consulting coming from manufacturers, distributors and users. Morgantiweb web is also the organizer of the "Morganti in Steel" fair, which is one of the biggest worldwide event focused on the steel chain; the company is strongly in favor of transparency and cooperative behavior, which inspired the national initiative above mentioned. In the future, digitization will allow a complete information gathering from the market.

Discussion and results

Manufacturing companies' supply chain is changing profoundly: until the first decade of this century, customers mainly ordered products from vendors, who ordered them from the makers. Warehouses were a fundamental asset for manufacturers to avoid stock outs. Production and assembly were scheduled to refill warehouses. At the same time, companies handled logistics and gathered feedback from customers to optimize the product's design and performance.

A modern supply chain has fewer steps, which are more direct and coordinated. Digitalization is reducing the role of physical warehouses and vendors: when a customer orders a product, design and sub-component customization start automatically, along with assembly and delivery (when needed).

Warehouses are no longer useful: a company orders production to its suppliers directly, and the latter provide the needed component on demand.

The information steps from start to finish shrink from four to two, with inevitable positive impacts on database management capabilities and lower delivery times for finished products. The figure shows a new supply chain configuration caused by the implementation of the new technologies for the digital transformation. In particular, the most important changes from the old structure are related to the management of the information between the actors long the entire supply chain. In fact, the central node of the supply chain, responsible for the assembling, has the possibility to interact directly with the final customers for the collection of the data and information about their needs towards the design phase, which becomes more important, with the utilization of the technologies like product configurator and 3D scanning which can improve the efficiency of this phase.

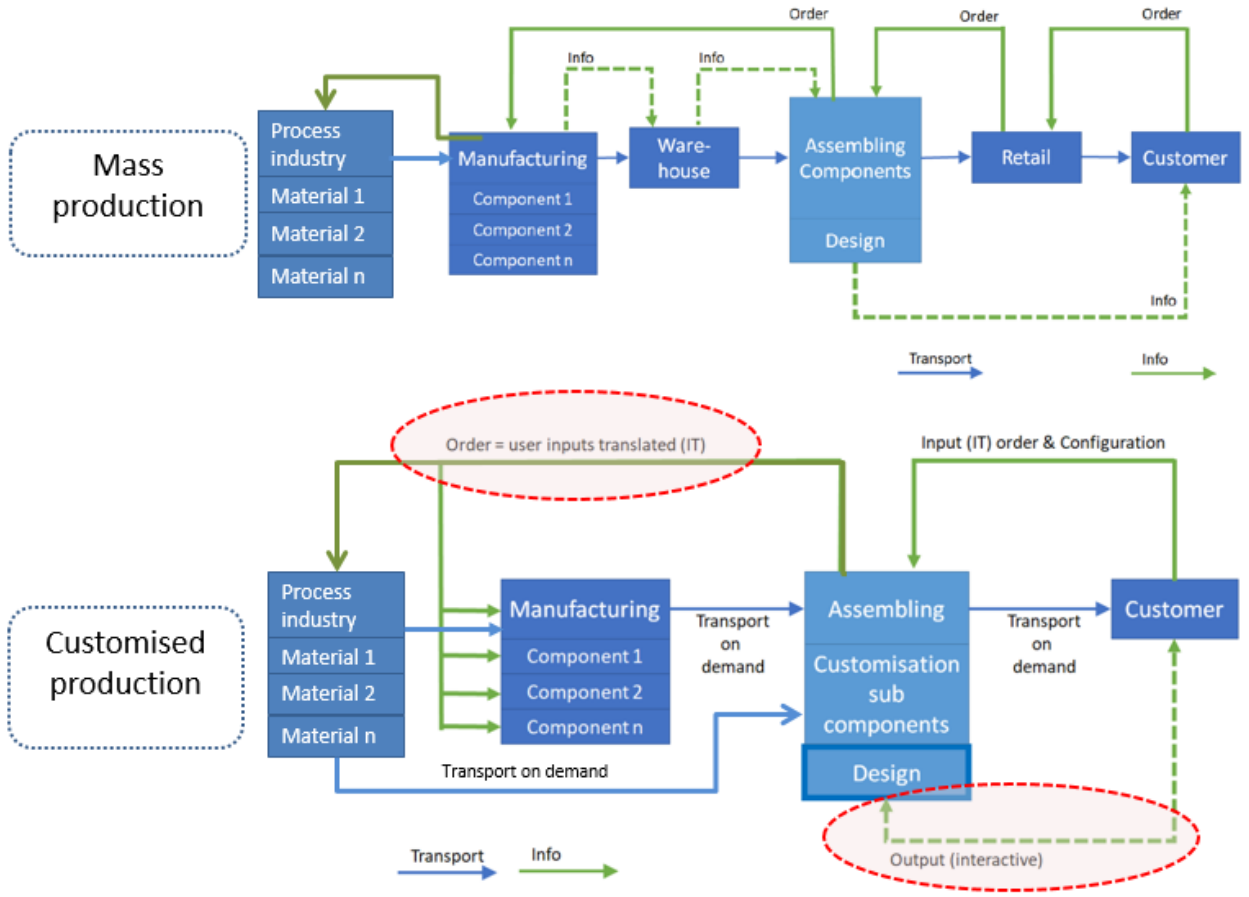

Figure 1: From mass production to customized production

All the data collected are then shared with the other actors along the supply chain until the suppliers in the upstream levels that are responsible for the manufacturing of the components and the production of the raw materials. The cloud based platform and the big data analytics permits to share data and the suppliers can have a vision on the final requests from the customers and a more efficient and coordinated management of the resources along the networks. In this way, digitalization is reducing the role of physical warehouses and vendors: when a customer orders a customized product, design and sub-component customization start automatically, along with assembly and delivery (when needed).

Technology classes

MC as a business model has implications on the offered variety of products and, going upstream, on the company's internal processes. In order to satisfy customers' heterogeneous requests, the internal processes themselves need to be changed and updated. Industry 4.0 is now a reality that all sectors are adopting, and using the right technologies for MC becomes mandatory.

According to our analysis, MC is supported by five technology clusters we will describe below. The first one comprises all manufacturing technologies, systems and equipment that are necessary to realize the customized products according to a flexible and reconfigurable approach able to handle small volume products with short delivery times. The second cluster addresses all supporting ICT technologies that have to be integrated in order to properly handle the information flow and the related increased amount of data that have to be managed when dealing with customized production. Technologies included in the Sustainability cluster are the ones that can help to face specific challenges connected with the production and dismissal of customized products. The Supply Chain Management cluster is strictly related with the equipment manufacturing and ICT ones because it deals with technologies and tools supporting the monitoring and control of the production flow along all the actors involved in the customization process. Finally, Design and configuration enable to enhance fundamental steps involved in customization as the product design, its configuration according to customer needs and the customer experience itself.

Clusters	Technologies
EQUIPMENT MANUFACTURING	Sensors, monitoring and control
	Adaptable and reconfigurable systems
	Multipurpose and hybrid processes
	Robotics
	Internet of Things
ICT	Modelling and simulations
	Big data
SUSTAINABILITY	Life Cycle Assessment
	Materials EOL (dismissal, recycling, separation)
SUPPLY CHAIN MANAGEMENT	Cloud based platforms
	Dynamic supply chain management
	Data mining
DESIGN AND CONFIGURATION	Product configuration
	Smart materials (sensor/bio based)
	3D scanning
	Virtual reality and Augmented reality

Table 1: Technologies divided per clusters

The analysis of the case studies and the relative technologies brought us to highlight some common aspects and some specific features of each one. The three companies are well positioned in the market, and they chose a clear and well-defined strategy, even while adapting to the dynamic economic environment. As described in the previous paragraph, five technology clusters that support MC have been identified. Moreover, for each cluster specific features have been described. In this section it is proposed a comparison of Industry 4.0 enablers with the elements of technology clusters identified giving on overview of possible connections.

The benefit to accelerate the shift of towards Industry 4.0 from science to reality in MC will allows practitioners and academicians to investigate the advent of a new production paradigm and its implication. In practice, new solutions must add value to users and must have an acceptable risk. The integration of Industry 4.0 solutions, which are generally linked to high investments, is especially lucrative in areas where cost-saving and simple methods such as Lean Manufacturing are not or not completely fulfilling today's requirements (Kolberg, D. et al., 2015). Within the Smart Factory equipped with sensors, microcontroller, actuators and a communication interface, CPS can work autonomously and interact with their production environment based on MC.

Industry 4.0 Enablers	**Equipment Manufacturing**	**ICT**	**Sustainability**	**Supply Chain Management**	**Design and Configuration**
Smart Products	- Internet of Things		- Life Cycle Assessment - Materials EOL		- Product configuration - Smart materials (sensor/bio based)
Smart Machines	- Sensors - Adaptable and reconfigurable systems - Multipurpose and hybrid processes - Robotics - Internet of Things				- 3D scanning
Smart Planner	- Internet of Things	- Modelling / simulations - Big data	- Life Cycle Assessment	- Dynamic supply chain management - Data mining - Cloud based platforms	
Smart Operators	- Control and Monitoring	- Modelling / simulations			- Virtual reality and Augmented reality

Table 2: Technology clusters that support MC

For this research, the four smart enablers for Industry 4.0 identified by department of Innovative Factory Systems at the German Research Center for Artificial Intelligence has been utilized (Lasi H. et al., 2014):

(1) *Smart Products* know their production process and negotiate it with the factory's equipment;

(2) *Smart Machines* are characterized by modular working stations based on standardized physical and IT interfaces, which can be flexibly reconfigured to new production lines via Plug'n'Produce;
(3) *Smart Planner* optimizes processes in nearly real time;
(4) *Smart Operators* who supervise and control ongoing activities supported by innovative ICT they become. In this environment, humans take a central position.

In the table 2, technology clusters' features are combined with Industry 4.0 enablers in order to highlight the possible connections in a synthetic overview.

Potential challenges and risks

The challenge of MC is linked to unpredictable and seasonal demand, which is difficult to be forecast. This reality is intensified by the fact that for example, consumer goods, in particular innovative and fashion products have in the last decades been facing the need of an increased number of product variants with a dramatic reduction of products life cycle. MC also brings its own set of challenges, from which we list the more representative as follows:

- The new paradigm of demand-driven supply networks emerges as a collaborative scheme to better respond to consumers' direct signals and needs. This represents a new challenge for companies, as they need to share more information with others (suppliers & competitors) to be able to answer to the changing needs;
- Development and implementation of innovative managerial models and methods to support collaborative practices downstream with customers and upstream with suppliers (Dyer and Singh, 1998; Camarinha-Matos et al., 2005);
- Increased number of SKUs could have an impact in the management cost (inventories, forecasting, procurement, customized pricing, etc.) that could exceed the expected benefits for companies in sectors where the production lead-time is long;
- Finding the optimal way of putting all the technological components together, into well integrated and scalable industrial technologies (Mironov et al., 2008);
- As product variety becomes larger (more customization), the unsold stock will be solved for some companies and would generally become more serious for others, as it is harder to manage the inventory of a larger portfolio, resulting generally on higher inventory levels when there are more products offered;

Conclusions

To provide a solution to the presented issue and the need for a fast adaptation from the companies and industries, two main results have been presented based on literature review, case studies, interviews with companies, and different industry reports. We described four archetypes, based on the mapping of recent trends (technological and non-technological) affecting business, and analyzed each of them in a real industrial context. Then we outlined a customized mass production scheme that represents the supply chain of the future.

Companies who have decided to include MC among their development strategies will have different impacts in a large variety of topics, such as customized production, materials management, waste reduction, etc. Therefore, here are presented the main impacts (positive and negative) at different levels that could come as result of its implementation.

The largest impact will happen in the following objectives:

- The production will become **more flexible** as the MC allows having different and innovative products, as well as an easiness for development of new products in virtually any location.
- Manufacturing will become **efficient and sustainable** as the design for new products will be made on computers before final printing (in the case of 3D printing), saving raw materials and reducing the amount of waste. In the case of other MC types, manufacturing will rely heavily on the supply chain (SC) configuration in the sense of selling a larger variety of the products using the same SC structure and standard modules and components.
- A minimization in the **time to market**, as product customization and new product development will happen faster.
- Minimized **response time to changes in demand as** result of understanding and providing the exact customized solution to the customer needs.
- Inclusion of **SMEs opportunities** will be a result of more variety of products, allowing these SMEs to become part of the conversation.

References

[1] Camarinha-Matos, Luis M., Fornasiero R., and Afsarmanesh H., "Collaborative networks as a core enabler of industry 4.0." Working Conference on Virtual Enterprises. Springer, Cham (2017)

[2] Panizzolo R., de Crescenzo A.M., Service Implementation Framework in Manufacturing Firms: A Case Study, Advances in Research, Vol. 11, No. 1, pp. 1-19 (2017)

[3] MacCarthy, Bart L., et al. "Supply chain evolution–theory, concepts and science." International Journal of Operations & Production Management 36.12 (2016)

[4] European Parliament - Directorate General For Internal Policies - Policy Department A: Economic And Scientific Policy, Industry 4.0 (2016)

[5] Boston Consulting Group. Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries (2015)

[6] Deloitte, Making it personal - One in three consumers wants personalised products, available at: https://www2.deloitte.com/uk/en/pages/press-releases/articles/one-in-three-consumers-wants-personalised-products.html (2015)

[7] Kolberg, D., and Zühlke, D., Lean automation enabled by industry 4.0 technologies. IFAC PapersOnLine, 48(3), 1870-1875. (2015)

[8] Lasi, H., Fettke, P., Kemper, H. G., Feld, T., & Hoffmann, M. "Industry 4.0. Business & Information Systems Engineering, 6(4), 239-242. (2014)

[9] Bocken, Nancy M.P., et al. "A literature and practice review to develop sustainable business model archetypes." Journal of cleaner production 65: 42-56 (2014)

[10] Forschungsunion/acatech. Securing the future of German manufacturing industry Recommendations for implementing the strategic initiative: INDUSTRIE 4.0 (2013)

[11] MacCarthy, Bart L., and P. G. S. A. Jayarathne. "Supply network structures in the international clothing industry: differences across retailer types." *International Journal of Operations & Production Management* 33.7: 858-886 (2013)

[12] Pedz, "Study on the Competitiveness of the EU tourism industry- with specific focus on the accommodation and tour operator & travel agent industries", Available at: http://www.pedz.uni-mannheim.de/daten/edz-h/gdb/09/executive_summary_en.pdf (2009)

[13] Mironov, V., et al. "Organ printing: promises and challenges." (2008): 93-103.

[14] Camarinha-Matos, Luis M., and Afsarmanesh H. "Collaborative networks: a new scientific discipline", Journal of intelligent manufacturing 16.4-5 (2005): 439-452.

Acknowledgements

This work has been partly funded by the European Commission through H2020 INSPIRE (Business Models for Flexible and Sustainable Manufacturing). This project has received funding from the European Union's Horizon 2020 Research and Innovation program under Grant Agreement n°723748.