# Investigating Supply Chains Models and Enabling Technologies Towards Collaborative Networks

# Investigating Supply Chains Models and Enabling Technologies towards Collaborative Networks


Elena Pessot[1,*], Andrea Zangiacomi[1], Frank Berkers[2], David Hidalgo-Carvajal[3], Ron Weerdmeester[4] and Rosanna Fornasiero[1]

[1] Institute of Intelligent Industrial Technologies and Systems for Advanced Manufacturing, National Research Council of Italy, via Alfonso Corti 12, 20133 Milan, Italy
{elena.pessot, andrea.zangiacomi, rosanna.fornasiero}@stiima.cnr.it
[2] TNO, Schoemakerstraat 97, 2628 VK Delft, Netherlands
frank.berkers@tno.nl
[3] GCLOG program, MIT SCALE Network, Massachusetts Institute of Technology, 1 Amherst Street, Cambridge, MA 02142
hidalgod@mit.edu
[4] PNO Consultants, Blijde Inkomstlaan 1, 1040 Brussels, Belgium
Ron.Weerdmeester@PNOCONSULTANTS.COM



**Abstract.** This research employs an extensive multiple case studies analysis to identify the most important business models affecting supply chain configurations and related enabling technologies towards the creation of collaborative networks. The results obtained from the investigation of 24 companies of manufacturing and process industry, informed by literature, identify four 'design principles' of business models, i.e. Personalized production, Servitization, Decentralized and modular production, and Recycle, Re-use and Sustainability. Each model is further described and discussed at the interplay between digitalization and collaborative network practices at supply chain level, showing that adopting one or the combination of the four design principles allows to actuate some of the most important features of collaboration like Vertical integration or networking of smart production systems, Horizontal integration through global value chain networks, Through-engineering across the entire value chain, Acceleration of manufacturing and Digitalization of products and services.



**Keywords:** Business models · Collaborative practice · Value Chain · Digitalization · Supply chain


## 1 Introduction

Companies need to promote an efficient and sustainable production of high added value goods to remain competitive in global markets and respond to the demanding requirements of consumers [1]. The market dynamics require companies to adapt their business and links within the existing supply chains towards new reconfigured network collaborations and business models that shift from cost competitiveness to cooperative efforts for a higher added value and competitiveness of the supply chain as a whole [2,3]. Along with this line, a greater vertical and horizontal integration between the involved actors should favor flexible, collaborative and interconnected networks of factories able to manage shorter cycles life of products while maintaining high levels of quality and resource efficiency [4]. Within this context, the digital technologies play a key role in enhancing the collaboration at value chain level and the integration of manufacturing and process sectors by improving flexibility and delivery of added value [4,5]. Supply chain models are thus evolving in order to benefit from technological innovation (and digitalization), with advantages in promoting a higher focus on customer requirements, improving efficiency in resource utilization, enhancing modularization of products and services [1], [5]. Indeed, the mega-trends identified in literature as reshaping the process and manufacturing sectors are digitalization, customization, resources optimization, servitization and modularization. Nevertheless, companies are still struggling to leverage or react to the shifts characterizing the actual competitive landscape and the way they do their business, and further research is required.

According to the depicted context, the aim of this study is to investigate the enabling technologies and main practices fostering collaboration at supply chain level, basing on the exploration of current practices of companies at the intersection of digitalization and collaborative networks (as in [2]). With this goal, the unit of analysis is represented by the business models emerging from the current trends and consequent opportunities leveraged by companies in their business. Specifically, design principles of business models have been identified and characterized in terms of main features, impacts on supply chain (supply and demand side), technologies and types of collaboration and integration towards digitalization.

## 2 Methodology

Aiming to perform an exploratory qualitative research, a multiple case study design [6] has been employed. We purposefully selected 24 among leading European companies of high value-added goods demonstrating to leverage on at least one of the main trends identified (i.e. digitalization, customization, resources optimization, servitization and modularization) as the base for the "design principles" to be followed in shaping their business model. A stratified sampling has been adopted in order to have a set of cases including different kinds of value chain partners (i.e. raw material providers, manufacturers, logistics providers, clients), types of manufacturing (process/discrete) and flexibility (e.g. capacity, product, location), sectors, to conduct a cross-sectorial and holistic investigation.

Table 1 provides an overview of cases basing on the integration of these variables.

Data collection was based on semi-structured interviews and secondary data (publicly available and internal documentation provide by interviewees), also for triangulation purposes [6,7]. Interviews have been conducted by the research team at company site or via Skype call and were based on a common protocol. Questions aimed at assessing the emerging supply chain configurations and business models basing on the combination of several dimensions of analysis: enabling technologies (with related readiness and impact on business model change), coordination and collaboration mechanisms along the supply chain, flexibility parameters to optimize flows in the value chain process, key activities involved in the delivery of value offer. Both multiple-choice (e.g. with provision of the list of technologies) and open questions were included, in order to enhance a further exploration of the real industrial cases. One to two respondents per each case were involved in the different interview meetings among the key roles in the digitalization, supply chain flows or strategy of their respective companies, e.g. CEOs, innovation, supply chain and operations managers.

**Table 1.** Overview of selected case studies.

| Case | Brief description of company main activity and industry |
|---|---|
| C1 | Leather fabrics supplier for customized consumer goods |
| C2 | Flexible manufacturer of customized shoes |
| C3 | Provider of rapid / additive manufactured components |
| C4 | Steel machineries manufacturer for customized small scale batches |
| C5 | Implantable drug delivery devices manufacturer |
| C6 | REE logistics provider for industrial symbiosis |
| C7 | Service provider for recycling tasks in chemicals |
| C8 | Recyclable packaging manufacturer |
| C9 | Aluminum printing plates provider, involved in recycle process |
| C10 | Polymers supplier, focused on sustainability |
| C11 | Mobile industrial processing of biomass |
| C12 | Water utilities provider, involved in re-use process |
| C13 | Processing of biomass flows into bio-based aromatics |
| C14 | Logistics provider of post-consumer textile waste |
| C15 | Pipeline transportation provider re-using residual gasses |
| C16 | Energy- and feedstock intensive company involved in industrial symbiosis |
| C17 | Metal and textile cleaning service provider |
| C18 | Provider of chemical leasing for metal cleaning |
| C19 | Remote chemical production control devices manufacturer |
| C20 | Provider of data analytics software for integrated plant-wide scheduling and control |
| C21 | Biopharmaceutical company developing transportable plants |
| C22 | Food company with flexible modular factory |
| C23 | Provider of equipment for container-based chemical manufacturing |
| C24 | Functional molecule production manufacturer with modular factory |

The collected data were qualitatively analyzed and coded independently by the researchers to identify common patterns and elements in the supply chain models, practices and enabling technologies. Emerging results were then compared until reaching agreement among researchers, and further presented and discussed in a workshop with experts from academic and industrial fields, aiming to assess their accuracy and significance for literature on collaborative network practices, digitalization and design principles of business models in a supply chain perspective.

## 3 Results

Results from pattern-matching and cross-case analysis [6,7], informed by current literature (e.g. [3], [5]) allowed to identify four main design principles of business models to frame the investigation: Personalized production, Servitization, Decentralized and modular production, Recycle, Re-use and Sustainability (RR&S). These business models are not completely independent from each other and are able to capture the majority of megatrends considered in the study even if they are addressing one of them in a more significant way than the others. This section includes the description of main features, involved value chain actors, type of collaborations and enabling technologies to activate each design principle of business model emerging from the analysis of the cases and the current trends in manufacturing and process industry.

A further analysis of the results, building on the work by [2], allowed to identify how the digital technologies adopted in the implementation of the four models enable the key features of collaborative models at the interplay with digitalization, i.e. Vertical integration or networking of smart production systems, Horizontal integration through global value chain networks, Through-engineering across the entire value chain, Acceleration of manufacturing and Digitalization of products and services.

### 3.1 Personalized Production

Customization has emerged over the past two decades as one of the strategies that allows companies to differentiate their offer through innovative products, where added value is given by meeting the specific needs of a customer or a target group of customers thanks to highly flexible manufacturing systems [8, 9]. The shift towards personalization is reinforced by new manufacturing technology developments, e.g. in advanced robotics, additive manufacturing and advanced digital simulation of manufacturing processes, enabling shorter production runs and more one-of-a-kind products [5]. Supply chains for personalized products enhance consumers to have products with a unique design and style, along with functional and comfort-related aspects, even in the more traditional sectors, and to make a choice in terms of value, functionality and performance [3].

**Enabling technologies for personalized production.** Enabling technologies include: 3D scanning, additive manufacturing (as 3D printing) and multi-purpose and hybrid processes for the production of customized components or products; virtual and augmented reality for supporting sales processes; modelling and simulation, business intelligence and sensors to enable changes in product and processes and reconfiguration of production networks; big data to optimize data driven manufacturing, better management of the innovation and the definition and analysis of the effects of location of the supply chain.

**Collaborative practices for personalized production.** In the attempt to rapidly reconfigure to satisfy custom requirements, the manufacturing systems should develop a high level of integration with customers/users, who become the main creators of the solution produced. For example, C2 developed direct customer relations by avoiding intermediaries as retailers and using on-line channels and platform strategy. Some technologies are also changing the relationships between business partners, as smart materials for C2: material suppliers are becoming technology providers, subject to strict selection and performance evaluation. Therefore, companies along the supply chain need to develop new business models and flexible manufacturing systems capable of producing relatively small batches of customized products at competitive costs, as C4, which outsourced both design and production of part of components to reduce complexity.

Basing on the analysis of the enabling technologies and practices, we can argue that the activation of the Personalized production model allows to realize the dimension of Horizontal integration through value chain, especially with customers for collecting their needs and integrate design activities through 3D scanning and big data analytics; the Through-engineering across the entire value chain thanks to collaborative product design and configuration, also with the use of smart materials; the digitalization of products and services through the use of Virtual reality and Internet of Things in supporting sales channels and design process.

### 3.2 Servitization

As more companies and industries in the world are increasingly adding value to their products by including additional services [10], the need for a clear business model becomes more relevant. This provides the opportunity for the development of servitization (also known as Product Service System (PSS) [11]) as a design principle that significantly changes the dynamics in a typical value chain, also in terms of services that could be oriented to the product, user, or result [12]. Companies are deciding to offer a broader set of products, ranging from mere products, to bundles of product-services and finally experience-based products and services [13,14]. Indeed, servitization leads the shift from a traditional linear supply chain centered on the product to a supply chain that increases the relevance of the services around the product, with key differences in terms of risks, responsibilities, ownership shared among the PSS provider and its partners in a value chain.

**Enabling technologies for servitization.** The technologies that have the largest impact in this model are focused on information sharing, monitoring and diagnostic, prognostic analysis and decision-support and include big data and big data analytics (with descriptive, predictive and prescriptive purposes), cloud computing and mobile platforms for customer communication and data access, IoT to enable automatic monitoring along the overall value chain, 3D printing for refurbishing, telemedicine and 360-degree medical data for the e-health services.

**Collaborative practices for servitization.** This design principle creates new relationships between a "supplier" and a "user/buyer", transforming the interaction usually based on single transactions into a long-term ongoing relationship, which can include the delivery of services, goods, management and knowledge. For example, C18 developed result-oriented servitization whereby the supplier and buyer collaborate in a form of payment called "paid per service unit", while reducing production costs and environmental impacts, improving expertise of both parts and optimizing processes. Beyond the strategy of the single company, the collaboration along the overall supply chain need to become more flexible and agile to incorporate a reconfiguration of the relationship between the manufacturer and the customer. C5 improved customer intimacy to grow trust, understanding of customer needs and faster achievement of outcomes through virtual communications.

It is possible to infer that the implementation of new technologies in this design principle will lead to develop of new services and complement current product offering, towards the dimension of Digitalization of products and services. Moreover, available technologies (Big data, Artificial intelligence, Automation, etc.) are becoming increasingly useful as they generate valuable information to the provider and generate an opportunity for a closer relationship with customer and for the dimension of Horizontal integration along product life-cycle, proving to be a key component in the introduction of new services.

### 3.3 Decentralized and Modular Production

Companies decentralizing their manufacturing split the production processes into smaller plants to produce in different locations or regions. Decentralized and modular production has effects on the organizational structure of companies, which can be more effective by focusing on their core activity, and on the value chain, which is broken down over more decision-making units that may be outsourced or procured at different locations. This shift leads to supply chains based on economies of scale and customer-specific, from process optimization to agile and distributed processing needs [15].

**Enabling technologies for decentralized and modular production.** Enabling technologies for this design principle need to support modularity, ICT for control, electrification, equipment manufacturing referred to novel inexpensive mass production technologies, process intensification and continuous processing and recovery/work-up. These include electrically powered chemical technologies, 3D printing and automated process control for manufacturing, and big data, skid based designs and plate based equipment for engineering.

**Collaborative practices for decentralized and modular production.** The business case of small-scale production is mainly focused on locating the production facility closer to the customer. For example, C21 is developing plants consisting of modular building blocks that can be easily extended to address increase in market demand or even adapted to fit in a container, to be easily transportable close to customer location. This changes a pivotal part of the supply chain in the manufacturing and sourcing stages. Also the container-base manufacturing in the value chain of C23 allows for local production and direct use of equipment and produced goods, with transportation discarded from the supply chain and consequent less impact on price volatility. Moreover, the decentralized supply chain is not fixed and can change based on the specific case at hand, with the large scale producer elements that can either be bypassed or integrated in the new supply chain.

Basing on the analysis of the enabling technologies and practices, we can argue that the activation of the Decentralized and modular production model allows to realize the dimension of Vertical integration, with the collaboration among small scale platforms, and the Acceleration of manufacturing, thanks to the increased use of technologies as electrically powered chemical technologies and multilayer disposable plants for small scale production.

### 3.4 Recycle, Re-use and Sustainability (RR&S)

RR&S business model is based on the principle of Circular Economy, where resource input and waste, emission, and energy leakage are reduced by slowing, closing, and narrowing material and energy loops [16]. The introduction of such a model has impact on both upstream (changed collaboration with raw material suppliers), downstream (collection of waste) and side stream (industrial symbiosis) value chain partners as well as on the value proposition (e.g. new recycling, extended producer responsibility or industrial symbiosis services), with closed material loops [17]. For example, C6 is creating new feedstock types based on waste, contributing to feedstock flexibility as well as environmental benefits with reduced impacts by providing alternative added value.

**Enabling technologies for RR&S.** Recycling refers to technologies that aim to recover materials from end-of-life products as disassembly and separation techniques. Technologies and solutions for industrial symbiosis represent an important area of development. Optimization of material use will increasingly see a combination of recyclability and biodegradable materials (e.g. in packaging). Novel “repair technologies” for industrial processes, such as 3D printing enable remanufacturing and repair. Key information and telecommunication technologies support the mapping, tracking and matching of materials throughout the supply chain. Moreover, data driven simulation of business model, product-ageing and reverse supply chain support decision making in the development and design of Circular Economy operations and organizations.

**Collaborative practices for RR&S.** The RR&S supply chain requires significant built of trust and collaboration among partners, from design for recycling up to dismantle for recycling (so called “reverse logistics”), from the planning and coordination of the circular supply chain to decision making in terms of remanufacturing, refurbishing and repair. It hence requires solutions that favor value chain coordination from end-of-life collection, treatment and re-introduction as a resource in the primary production process. For example, C13 is innovating the process to be more efficient, introducing new actors in the value chain, reinforcing relationships with neighboring industries and redefining capacity, location and feedstock flexibility for maximizing sustainability and recycling opportunities.

It is possible to infer that the implementation of an RR&S business model allows to enable more than one dimension of collaborative networks, i.e. Horizontal integration, also thanks the adoption of trusted cloud based platforms, e.g. for waste value chain management, the Vertical integration through product-ageing simulation, and Acceleration of manufacturing through selective separation technologies and automated disassembly.

## 4 Discussion and Conclusions

This study performed a broad investigation of 24 companies of manufacturing and process industry to identify the most important business model affecting supply chain configurations and related enabling technologies towards the creation of collaborative networks. Basing on this analysis, we can argue that the four design principles analyzed enable all the characteristics of collaborative networks for the digitalization of the overall value chain, i.e. Vertical integration or networking of smart production systems, Horizontal integration through global value chain networks, Through-engineering across the entire value chain, Acceleration of manufacturing and Digitalization of products and services, and the integration of the manufacturing and process industry. Design principles are addressed to any type of collaborative network described in [2], i.e. one business model (design principle) does not preclude the implementation of one collaborative network or another. Moreover, the enabling technologies should be targeted for sustaining specific collaborative practices, but also developed in a systemic perspective for enhancing the overall supply chain performance.

Obtained results contribute to advance knowledge in the research on digitalization and collaborative networks by adopting a perspective integrating business model design principles, enabling technologies and collaborative practices implemented at the value chain level. Managers should develop one or a combination of these design principles on the basis of company's competitive priorities, while considering the value chain perspective, in order to foster practices with downstream and upstream actors enabling the digitalization and the implementation of a holistic collaborative network approach. Even if design principles identified in the empirical investigation are not completely new, the originality of the paper consists in providing industry practitioners with examples that can be considered and configured in their own contexts as a sort of 'working ingredients' clustered around the design principles identified. An expected impact is a wider adoption of the business models guiding supply chains configurations towards collaborative networks, in order to improve competitiveness and resilience of European industry in dealing with major industrial challenges.

A recognized limitation of the study concerns the methodology and the sampling adopted that can pre-determine to some extent the emerging patterns of design principles. Nevertheless, the focus is on the exploration of the design principles at the base of supply chains configuration to foster their adoption towards collaborative networks, rather than the identification of the principles themselves.

**Acknowledgments.** This research has been conducted as part of the INSPIRE project, which has received funding from the European Union's Horizon 2020 Research and Innovation program under Grant Agreement n°723748. The authors wish to acknowledge their appreciation to the European Commission for their support and to all the project team for their contribution during the development of this research.

## References

1. Ben-Daya, M., Hassini, E., Bahroun, Z.: Internet of things and supply chain management: a literature review. Int. J. Prod. Res. DOI: 10.1080/00207543.2017.1402140 (2017)
2. Camarinha-Matos, L.M., Fornasiero, R., Afsarmanesh, H.: Collaborative Networks as a Core Enabler of Industry 4.0. In: Camarinha-Matos, L., Afsarmanesh, H., Fornasiero, R. (eds) *Collaboration in a Data-Rich World*. PRO-VE 2017. IFIP Advances in Information and Communication Technology, vol 506. Springer. DOI: 10.1007/978-3-319-65151-4_1 (2017)
3. Fornasiero, R., Zangiacomi, A., Franchini, V., Bastos, J., Azevedo, A., Vinelli, A.: Implementation of customisation strategies in collaborative networks through an innovative Reference Framework. Prod. Plan. Control 27(14), 1158-1170 (2016)
4. Büyüközkan, G., Göçer, F.: Digital Supply Chain: Literature review and a proposed framework for future research. Comput. Ind. 97, 157-177 (2018)
5. Ivanov, D., Dolgui, A., Sokolov, B.: The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics. Int. J. Prod. Res. DOI: 10.1080/00207543.2018.1488086 (2018)
6. Yin, R.K.: Case Study Research: Design and Methods (Fifth Edition). Thousand Oaks, CA: SAGE Publications (2013)
7. Voss, C., Tsikriktsis, N., Frohlich, M.: Case research in operations management. Int. J. Operations Prod. Mngmt. 22(2), 195-219 (2002)
8. Ivanov, D., Das, A.,Choi, T. M.: New flexibility drivers for manufacturing, supply chain and service operations, Int. J. Prod. Res. 56(10), 3359-3368 (2018)
9. Montalto, A., Graziosi, S., Bordegoni, M., Di Landro, L., van Tooren, M. J. L.. : An approach to design reconfigurable manufacturing tools to manage product variability: The mass customisation of eyewear. J. Int. Manuf. 1-16, (2018)
10. Vandermerwe, S., Rada, J: Servitization of business: Adding value by adding services. Europ. Mngmt. J. 6(4), 314-324 (1988)
11. Goedkoop, M. J., van Halen, C. J., te Riele, H.R., Rommens, P.J.: Product Service systems, Ecological and Economic Basics. Amersfoort: PRE consultants (1999)
12. Reim, W., Parida, V., Örtqvist, D.: Product–Service Systems (PSS) business models and tactics – a systematic literature review. J. Clean. Prod. 97, 61-75 (2015)
13. Hassenzahl, M., Diefenbach, S., Göritz, A.: Needs, affect, and interactive products – Facets of user experience. Int. Comp. 22(5), 353-362 (2010)
14. Kimbell, L.: Designing for Service as One Way of Designing Services. Int. J. Des. 5(2), 41-52 (2011)
15. Srai, J.S., Kumar, M., Graham, G. et al.: Distributed Manufacturing: scope, challenges and opportunities. Int. J. Prod. Res. (2016)

16. Witjes, S., Lozanoa, R.: Towards a more Circular Economy: Proposing a framework linking sustainable public procurement and sustainable business models. Res. Conserv. Recycl. 112, 37-44 (2016)
17. Bocken, N.M.P., de Pauw, I., Bakker, C., van der Grinten, B.: Product design and business model strategies for a circular economy. J. Ind. Prod. Eng. 33(5), 308-320 (2016)