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The impact of data-driven technologies on supply chain design

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Short Paper

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Abstract

Recent supply chain disruptions following Covid-19 and international crises have led to changing paradigms in supply chain design. Likewise, data-driven technologies housed under the term Industry 4.0 have an increasing impact on how supply chains are orchestrated and shaped. This paper gives an overview to several examples of recent and expectable trends in supply chain design. Advanced manufacturing technologies, data-driven technologies in logistics and supply chain management, electrification of vehicles, as well as microchips and semiconductor manufacturing are described as representative drivers of new forms of supply chain design. In this context, a special emphasis is devoted to European initiatives such as the European Chips Act or the European Battery Alliance. Examples such as manufacturing ecosystems or platform-based manufacturing are given as well as locally independent supply chains that provide potentials for supply resilience and sustainability. The paper concludes with a research agenda that includes seven areas for future research, including changes in supply chain structure, changes in inter-firm interaction, integration of small and medium-sized enterprises, changing roles of humans and new forms of business models and collaboration. In this context, the interrelations between technologies (product and production level) as well as the research avenues must be emphasized.

Keywords: Data-driven technologies, Industry 4.0, Industrial Internet of Things, Digital Transformation, Supply Chain Management, Supply Chain Design

Introduction

The manufacturing industry is undergoing significant technological transformation processes. These represent both an opportunity, but also significant challenges. Several initiatives, for example, the Industry 4.0 initiative originally launched by the German government aim to maximize the benefits of introducing new technologies to manufacturing enterprises. Further, they aim for maintaining competitiveness of manufacturing in high-wage countries and to relocate manufacturing and jobs to Europe (Kagermann et al. 2013). For instance, backshoring and reshoring have been used to describe manufacturing relocation that includes job relocation at the same time (Stentoft and Rajkumar, 2020; Strange and Zucchella, 2017).

The relocation of manufacturing and jobs to high-wage countries reverse, to some extent, the globalization and outsourcing trend that has been observed in the previous decades (Ellram et al., 2013). Further drivers for this are value chain disruptions due to Covid-19, which lead value chain design towards more resilience, rather than primarily cost effectiveness (Barbieri et al., 2020). Comparably, the concept of the Circular Economy and societal demand towards sustainability may lead value chain design towards proximity. This localization aims to place value creation more closely to consumption again. This is as after years of outsourcing and relocating manufacturing to low-cost countries and an increasing globalization of supply chains, supply chain design is challenged by current crises and events such as Covid-19, demanding higher supply chain resilience (Spieske and Birkel, 2021).

Conclusively, several external drivers such as current crises, Covid-19 or demands for more sustainable supply chains drive supply chain redesign. Likewise, technological transformations in manufacturing, but also in industries such as the automotive industry or semiconductor or microchip manufacturing drive supply chain redesign. Figure 1 gives as overview of these developments.

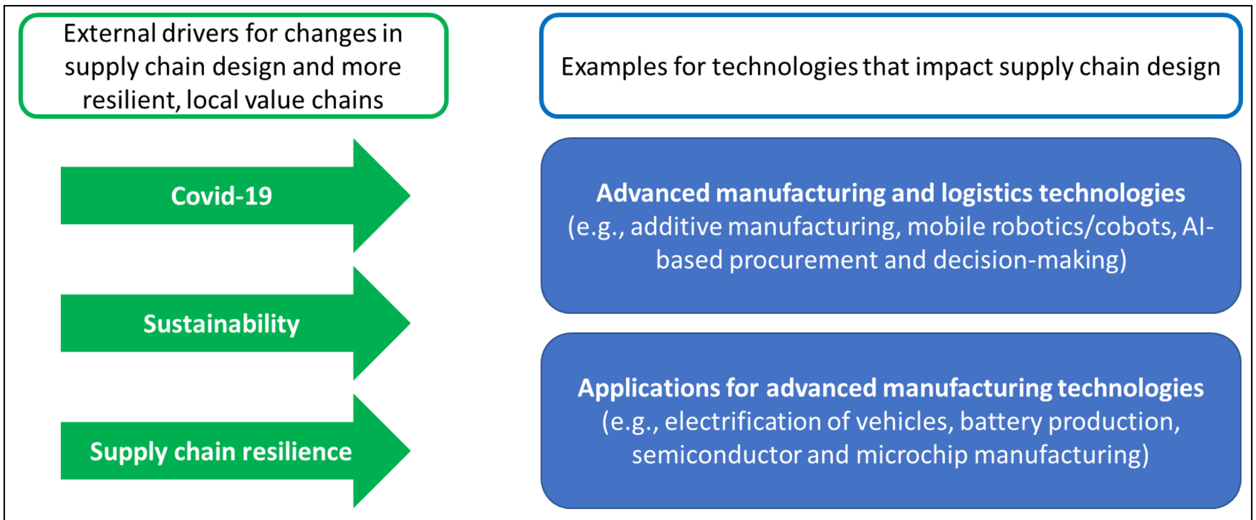

Figure 1. Overview of external drivers and technologies that impact supply chain design

The next section gives an overview on examples that are referred to on the right side of Figure 1 (in blue), advanced manufacturing technologies, data-driven technologies in logistics and supply chain management, electrification of vehicles, as well as microchips and semiconductor manufacturing.

Examples for technologies impacting supply chain design

The following examples, advanced manufacturing technologies, data-driven technologies in logistics and supply chain management, electrification of vehicles, as well as microchips and semiconductor manufacturing do not represent an extensive list but highlight changes and interdependencies of technologies and transformations that impact supply chain design. A special focus is given to European initiatives in this regard, while comparable programs and initiatives can be observed globally.

Advanced manufacturing technologies

As a prominent example, additive manufacturing (also known as 3D printing) already reshaped the manufacturing locations of spare parts. Instead of a traditional manufacturing value chain, production is now possible directly where spare parts are required (Ancarani and Mauro, 2018; Dachs et al., 2019). For instance, melting and metal treatment as traditional process steps can be omitted. This leads to more efficient processes, but several suppliers are not required anymore (Delic and Eyers, 2020; Tziantopoulos et al, 2019). Comparably, collaborative robots ("cobots") or mobile robotics technologies in manufacturing change required job profiles. They partially replace but also complement human capabilities. In a positive sense, human capabilities are enhanced, and training is improved. Whereas the reduction of repetitive tasks as such is an advantage, this also threatens existing jobs, especially in high-wage countries (Frey and Osborne, 2017).

Data-driven technologies in logistics and supply chain management

Concomitant with advanced manufacturing technologies, data-driven technologies housed under the term Industry 4.0 begin to shape supply chains (Stentoft and Rajkumar, 2020; Strange and Zucchella, 2017). New forms of decision-making in procurement and logistics processes alter supplier selection, interactions between buyers and suppliers, and the structure of supply chains. This development is accompanied by developments towards manufacturing ecosystems or platform-based manufacturing that enables interaction between several actors and stakeholders of supply chains rather than linear interaction. Technological enablers include the Internet of Things which interconnects several supply chain partners and offers supply chain transparency that can be utilized using artificial intelligence or big data analytics (Schmidt et al., 2022; Veile et al., 2022).

Electrification of vehicles

The electrification of vehicles leads to a significant reduction of the number and type of components required. In comparison to cars with internal combustion engines, the number of mechanical parts decreases (Pinkse et al., 2014). This will reduce the complexity of components and thus the number of working hours required. Therefore, European car manufacturers and their suppliers fear that jobs or entire industry sectors will be lost or relocated. This is as new competencies required, such as for battery production, are notably stronger outside Europe. Further, the required rare metals for electric motors and batteries can hardly be mined in Europe (Fragkiadakis et al., 2020; Habib et al., 2020). To counter this, the European Union drives several programs subsumed under the European Battery Alliance (European Commission, 2017). It aims to establish manufacturing capacities in Europe based on locally available resources and know-how (Beuse et al., 2018; European Commission, 2017). In this regard, the electrification of vehicles is not only a field of technological developments in the automobile, but also requires advanced manufacturing technologies and data-driven technologies in logistics and supply chain management, such as for the battery. This is as batteries for cars have increased demand for data integration in order to repair and recycle battery cells based on demand and usage.

Figure 2 below illustrates the demand for microchips in automotive manufacturing, highlighting the interdependencies between the electrification of vehicles described in this section and microchip and semiconductor manufacturing described in the following section (ASML, 2022). While electric cars will require additional and more advanced microchips, especially autonomous driving will lead to increased demand and high performance in automobiles. Notably, automobiles rather require less sophisticated microchips in comparison to, e.g., consumer electronics.

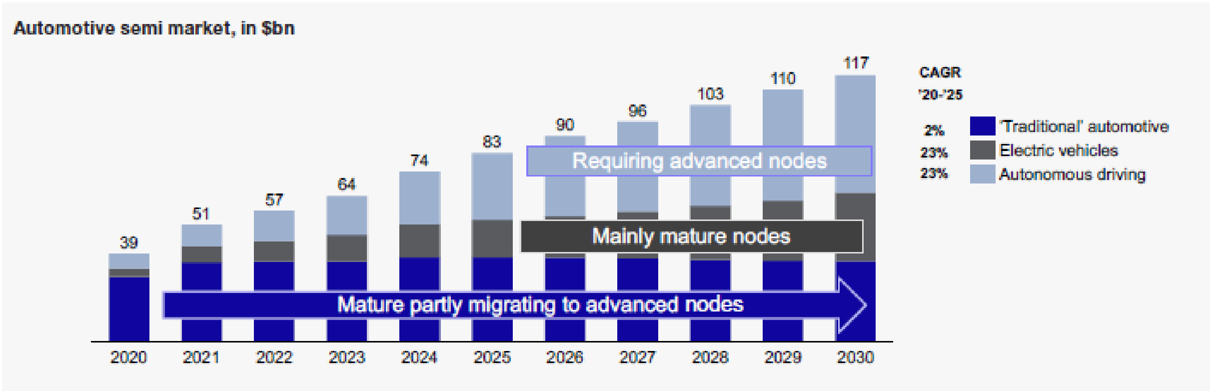

Figure 2. Microchip manufacturing capacities worldwide (ASML, 2022)

Microchip and semiconductor manufacturing

The European Chips Act describes a program of the European Commission to relocate semiconductor and microchip manufacturing capacities increasingly back to Europe, where those are demanded for, e.g., automotive or machinery production. They are driven by the microchip shortage beginning in 2020 which has severely impacted manufacturing globally and highlighted dependency on Asian countries. Notably, the manufacturing of microchips is largely dependent on one single European manufacturer supplying the machines for microchip wafer production (ASML, 2022; European Commission, 2022; Hancké and Garcia Calvo, 2022). Comparable programs worldwide such as in the US drive manufacturing relocation with similar goals.

Figure 3 below highlights the development of manufacturing capacities for microchips with a forecast until 2030. China, Taiwan, South Korea and Japan represent to three quarters of global microchip manufacturing capacities, while they are demanded equally by, e.g., European and US manufacturers. Disruptions in supply chains mean that microchip production in Asia is potentially too far from European and US manufacturing (ASML, 2022).

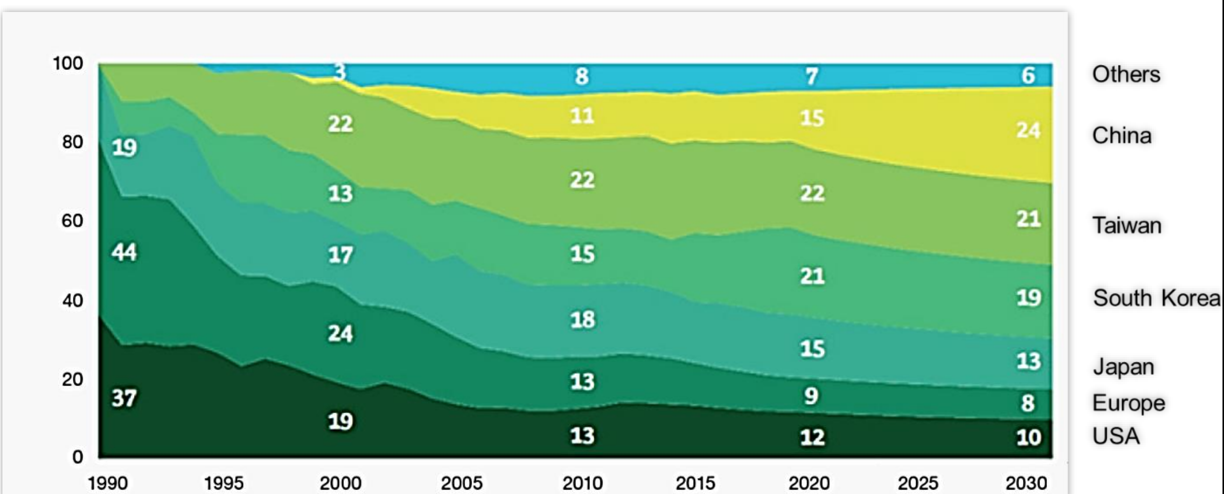

Figure 3. Microchip manufacturing capacities worldwide (ASML, 2022)

Potential effects on supply chain design

While exact effects are still unclear and disputed, feared effects largely influence the behavior of industrial manufacturers, workers and trade unions, public opinion, and policymakers (Frey and Osborne, 2017). A comprehensive analysis is especially relevant as several initiatives for manufacturing and job relocation have not been particularly successful. A prominent example is the attempted build-up of a solar industry in Europe. Still, it is primarily located in Asia, mainly China (Georgallis et al., 2021). With the manufacturing industry and automotive industry, so far prosperous sectors are undergoing transformations in the upcoming years.

Manufacturing ecosystems and platform-based manufacturing

One trend to be expected is the transformation towards manufacturing ecosystems and platform-based manufacturing in contrast to linear supply chains (Schmidt et al., 2022; Veile et al., 2022). Likewise, new forms of collaboration between stakeholders, such as small and medium-sized enterprises and their integration on such platforms as well as entrants like data-driven companies to traditional manufacturing sectors must be considered (Kazantsev et al., 2022). This will, in turn, lead to new forms of supply chain interaction and design with numerous interdependent effects (Schmidt et al., 2022). Several potential areas of research based on developments to be expected in this regard are described in the research agenda following this section.

Locally independent supply chains

Further, based on the four examples described in the sections above, locally independent supply chains describe a potential transformation in supply chain design. To accommodate for more resilient and sustainable supply chains, i.e., moving manufacturing closer to consumption, locally independent supply chains could represent a trend in the upcoming years. Those are characterized as independent regarding resources, manufacturing and demand and thus increasing resilience, standardization and synchronization and could thus accommodate for crises such as natural disasters. For instance, three independent areas for manufacturing and demand in the Americas, Europe and Africa, as well as Asia could represent a future development as illustrated in Figure 4 below.

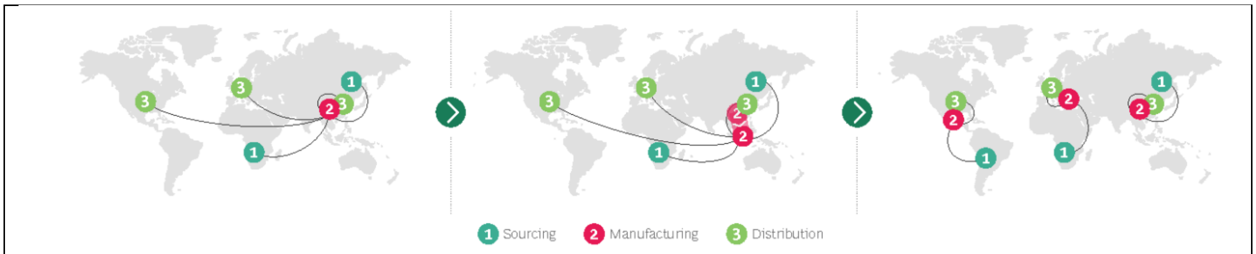

Figure 4. Manufacturing relocation leading to locally independent supply chains (BCG, 2020)

Research Agenda

Table 1 below subsumes several studies on data-driven technologies in manufacturing and logistics supply that can be expected to alter supply chain design.

Table 1. Research Agenda

Areas for future research	Exemplary Publications	Descriptions and examples for future research areas
I) Changes in supply chain structure	Stentoft and Rajkumar (2020); Strange and Zucchella (2017)	• Manufacturing relocation based on the integration of new technologies on production level (e.g., advanced manufacturing technologies, data-driven technologies in procurement and logistics) • Transformation of industrial sectors based on new technologies (e.g., electrification of vehicles, semiconductor and microchip production)
II) Changes in inter-firm interaction and supply chain design	Schmidt et al. (2022), Veile et al. (2022)	• Impacts and effects of buyer-supplier relationships and interactions • Supply chain collaboration in manufacturing ecosystems and platform-based manufacturing
III) Supply chain resilience and sustainability	Barbieri et al., 2020; Spieske and Birkel (2021)	• Effects and interrelations of supply chain resilience among the above-described areas • Learnings from extant crises and those to be expected for supply chain design • Supply chain sustainability as a further driver of supply chain design
IV) Integration of Small and medium-sized enterprises	Estensoro et al. (2022); Kazantsev et al. (2022); Lassnig et al. (2022)	• Accessibility of small and medium-sized enterprises to manufacturing ecosystems and platform-based manufacturing approaches • Stepwise and adaptive (“downgraded”) implementation approaches for small and medium-sized enterprises with respect to requirements of customers and entire supply chains
V) Manufacturing operations and supply chain design	Lerman et al. (2022); Spieske and Birkel (2019)	• Interrelations between manufacturing, procurement, and logistics processes and their digital integration • Implications for supply chain design including further company functions (e.g., product development, recycling and Circular Economy)
VI) Changing roles of humans	Schmidt et al. (2022); Veile et al. (2022)	• Trust and information exchange in digital interaction as enablers and results of changes in supply chain interaction and design • Smart contracts and automated negotiations and their implications for the role of humans
VII) New forms of business models and collaboration	Kazantsev et al., (2022); Müller and Buliga (2019)	• Platform-based and ecosystem-based manufacturing business models which lead to changes in supply chain design • Collaboration among multiple actors (e.g., small and medium-sized enterprises) and implications of supply chain structure and design

Conclusion

This paper introduces four examples of technological transformation processes that alter supply chain design: Advanced manufacturing technologies, data-driven technologies in logistics and supply chain management, and electrification of vehicles. Further, current demands towards supply chain resilience following current crises and Covid-19 concomitant with demands towards supply chain sustainability and supply chain design towards the Circular Economy are described. Highlighting the respective interdependencies, the paper develops a research agenda for future studies and the intersection of data-driven technologies housed under the term Industry 4.0, technological transformation processes in several industries, and demands towards future resilient and sustainable supply chains.

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