Supply network design for Industry 4.0: Lessons learned from German manufacturing industries

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Abstract

Industry 4.0 presupposes full flexibility in supply network design to fulfil vastly individualized customer requests. While Industry 4.0 can open new business models, the supply network design is challenging: the role of the focal firm as principal coordinator becomes increasingly decentralized, interface standards are missing, and big data analysis for the necessary real-time coordination bears algorithmic challenges. This paper presents results of a longitudinal meta-study on development and current state of Industry 4.0 in the German manufacturing industries. The author derives lessons learned and best practices for supply network design in Industry 4.0 settings.

Keywords: Industry 4.0, platforms, manufacturing industries

Introduction

Industry 4.0 moves away from the idea of supply chains being processes with specific beginnings, pre-determined process steps and a specified end. Instead, it presupposes the highest degree of flexibility to fulfil vastly individualized customer requests (batch size of 1). Such flexibility not only requires a set of actors that come together to bring that particular product or service to market, but their selection from a larger set of potential actors on a one-on-one basis. While Industry 4.0 can open new business models, the technical implementation and especially the supply network design and the operations strategies for providing highly individualized products and services is challenging. In particular, the role of the focal firm as coordinator and central decision maker becomes increasingly decentralized.

Therefore this paper portrays the background of the Industry 4.0 concept and investigates how it developed in the German manufacturing industries in the past five years. It derives lessons to be learned from the development and best practices for supply network design and operations strategies in Industry 4.0 settings.

The concept of industry 4.0

Origins

The German government coined the term Industry 4.0 (I4.0) in a high technology strategy project to address the increasing global competition on product quality and production costs faced by the German manufacturing industry (Lee et al. 2015; Müller et al. 2017; Rodriguez et al. 2018). I4.0 was first presented to the public at Hannover Industrial Fair 2011 as part of the High-Tech Strategy Action Plan 2020 (Helmold &

Terry 2016). Germany's very important manufacturing sector suffered through the relocation of production facilities towards aspiring countries, which had managed to close the productivity and quality gap while keeping labour costs comparatively low. At the same time, established manufacturing companies had to recognize that customers were no longer willing to pay large price premiums for incremental quality improvements and demanded customized products and fast delivery (Brettel et al., 2014; Helmrich 2017). Consequently, manufacturing companies started to exploit new business potentials and opportunities through emerging technologies such as digitalization, the internet of things (IoT), internet of services (IoS) or cyber-physical systems (CPS). Against this backdrop, Germany launched the "Industrie 4.0" initiative as part of its high-tech strategy to establish itself as a leader of integrated industry. Since then, I4.0 has received growing attention (even keeping the original German spelling for the long version) and was recorded on the 2016 World Economic Forum's agenda (Hofmann & Rüsch 2017).

Definition

Most surprisingly, although the concept Industrie 4.0 is now widely discussed, there is still no generally accepted understanding of what it comprises, neither in academia nor in practice (Hofmann & Rüsch, 2017; Vogel-Heuser & Hess (2016), Xu et al., 2017). Interviews with practitioners commonly reveal a fuzzy image of I4.0 regarding the actual objectives, the relevant technologies, or the applicability for different industrial sectors. Similarly, academics have not developed a sound conceptual and terminological foundation of I4.0, which consequently hampers scientific research (Hermann et al., 2016).

Based on Spath et al. (2013), Bauernhansl et al. (2014) and Müller et al. (2017) this paper defines Industrie 4.0 as a concept in which companies, machines, devices and computers cooperate through digital technologies in horizontal and vertical networks to manufacture highly-individualized products. By connecting plants, equipment, machines, products and workpieces through information and communication technologies (ICT) into cyber-physical systems these networks continuously share information in real-time. As smart manufacturing conveys the same ideas as I4.0 (Kusiak 2017), both terms will be used interchangeably in this paper.

The author proposes to capture the I4.0 concept into four components: business models, enablers, information, and network management (see figure 1), which are subsequently explained.

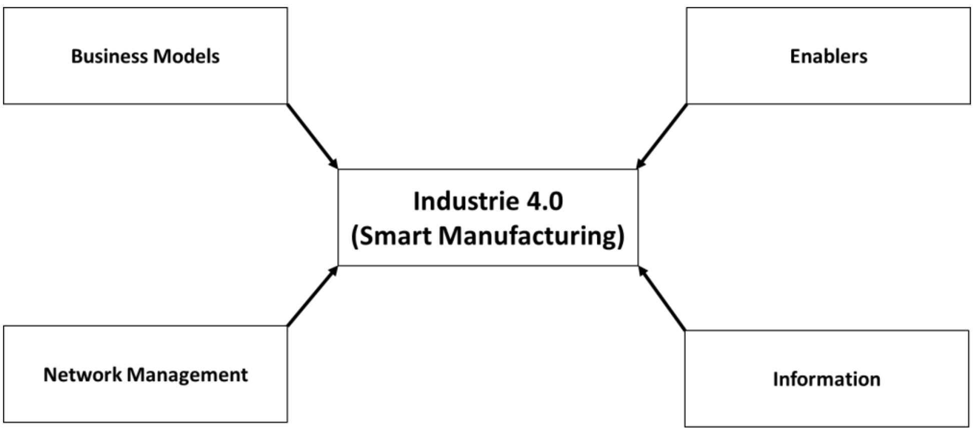

Figure 1: Components of the industry 4.0 concept

Business Models

From a business model perspective I4.0 either addresses cost reductions or capturing new business opportunities such a innovative products and services. Currently most manufacturers focus on the latter while business model innovations are moving at a slower pace (Ernst & Young, 2017; Goschy & Rohrbach 2017; Rodriguez et al., 2018).

The majority of new business models involves data analytics. For analytic and predictive maintenance, the collected data is analysed to offer customers improved information on process status or replacement suggestions for their equipment, hence adding a service component to the pure product. Extended models move to a full service offer where the customer no longer buys the equipment but only pays for equipment use. Essentially a service now replaces the product offer (everything as a service, aaS).

From a cost reduction perspective, I4.0 is regarded as a means to improve processes or increasing production flexibility and adaptiveness, faster reaction times or an improved overall effectiveness of manufacturing equipment (Buer et al., 2018, Liao et al., 2016; Lu 2017).

Network Management

A major challenge is to determine the best real-time combination of actors regarding objectives such as timing, cost, quality levels, etc. for each individual order. Such a multitude of objectives can only be achieved through extended vertical, horizontal, and lateral collaborations resulting in growing complexities of value creation settings with multi-level competition and ensuing transaction costs (Dietl et al., 2009, Holweg et al. 2014). As a result, actors face a trade-off between installing efficient supply networks for particular products while being flexible enough to be part of alternative supply networks for required product differentiations (Brusoni et al., 2009, Jia et al. 2017, Pullman et al., 2010, Stevenson et al., 2017). In addition, the role of the focal firm as principal coordinator becomes increasingly decentralized in I4.0 settings. These challenges add to those discussed in the supply network design and operations strategy literature (Holweg et al., 2014, MacCarthy et al., 2016, Pashaei et al., 2017).

Enablers

I4.0 grounds in a variety of enablers, which are briefly described in the following passage. A more detailed description and evaluation of I4.0 enablers can be found, for example, in Schebek et al. (2017) or Plattform Industrie 4.0 (2016).

Cyber-physical systems (CPS): CPS are systems that connect computation with physical processes. In the context of manufacturing this refers to monitoring and controlling the processes via computer networks (through the use of multiple sensors, actuators, control processing units, and communication devices) and synchronising information related to the shop floor (Lee et al., 2015; Mosterman & Zander, 2016). Technologies such as RFID tags allow unique identification, while multiple sensors and actuators not only provide storage and data analytics, but are fully network compatible (Hermann et al., 2016). So-called manufacturing execution systems (MES) are the critical module that function as interoperational, real-time-enabled, and web-enabled connector between enterprise resource planning (ERP), production planning and control (PPC), and the actual shop floor, thus ensuring the connection of all network participants (Obermaier & Kirsch, 2017). Consequently, manufacturing equipment will turn into CPPS, Cyber-Physical Production Systems, that know their state, their capacity and their different configuration options and are able to take decisions autonomously. In the I4.0 concept the shop-floor will become a marketplace of capacity (supply) and demand with multi-agent systems self-organizing allocation (Almada-Lobo, 2016).

Internet of Things (IoT): The idea of smart, connected products is considered an initiator of Industry 4.0. IoT refers to a setting where essentially all (physical) things can turn into so-called "smart things" by featuring RFID tags, sensors, actuators, or small computers that are connected to the internet (Keskin & Kennedy, 2015). Through unique addressing schemas, these components interact with each other and cooperate with their neighbouring 'smart' components in order to reach common goals (Hermann et al., 2016). IoT is at the heart of business models relying on new functionality, improved reliability, higher product utilization and capabilities (Greiner, 2015; Hofmann & Rüsch, 2017).

Internet of Services (IoS): The idea behind IoS is to make services easily available through web technologies (such as service-oriented architecture (SOA) or software as a service (SaaS)), allowing companies and consumers to create new kinds of value- added services. These services provide access to the resources of another party in order to perform a prescribed function and receive a related benefit. Resources may be human workforce and skills, technical systems, information, consumables, land, etc. (Hofmann & Rüsch, 2017).

Smart factory: The idea of the smart factory conveys a decentralised production system that is made up of a network of human beings, machines and resources that communicate with each other as naturally as in a social network (Yin et al., 2017. The existing production logic with a central steering entity changes towards smart products that navigate their way independently through production processes and are easily identifiable and locatable at any time. Digital connectivity enables an automated and self-optimised production of goods and services including delivering without human interventions (self-adapting production systems based on transparency and predictive power) (Hofmann & Rüsch, 2017). Besides these changes in production processes also the roles of employees are expected to alter with employees taking on more supervising tasks with greater responsibility (Spath et al., 2013). They are supported by smart technologies such as wearables (e.g. smart watches, glasses, or gloves), augmented reality applications, autonomous vehicles (incl. drones) and distributed ledger systems (e.g. the blockchain). Data analytics amalgamates the information from these connected systems to provide decision support to both machines and humans.

Information

I4.0 depends on extensive data analytics. In a first process step data is being collected via multiple devices. Data analytics then inspects, cleansies, transforms, and models data in order to discover patterns, extract relevant information, and support decision-making. Typical techniques involve data mining, which mostly focuses on data analysis for predictive purposes, and statistical applications, which focus on discovering previously unknown facts, structures, or evidence. Other common techniques are data visualization and data dissemination.

Design/methodology/approach

In a longitudinal meta-study, the author traces the development of the Industry 4.0 concept and its implementation in the German manufacturing industry over a period of five years based on archival data, case studies from the automobile industry and a medium sized (plastics) manufacturer, semi-structured interviews, and field observations. Germany was selected as the concept originates in this country. Due to space limitations this paper focuses on presenting a condensed overview of the results of the meta-study and the automobile industry case study.

Industry 4.0 lessons learned from German industry

Optimistic studies estimate German manufacturers on average can nearly double their operating profit through smart manufacturing (Cap Gemini Consulting, 2018). At the same time manufacturers become gradually aware that technological changes do not only bear great potential, but do come with considerable risks of disruption. Almost 60% of manufacturers anticipate disruptive attacks in the next ten years (Goschy & Rohrbach, 2017). Consequently, increasing investment into I4.0 technologies is expected for the near future, particularly for SME. On average 5% of turnover will likely be invested, primarily for personnel and ICT. In terms of outcomes the highest potential is expected for increasing flexibility in production and logistics (Ernst & Young, 2017), predictive maintenance on both the production and product side (Goschy & Rohrbach, 2017), and the development of new business models (Bundesministerium für Wirtschaft und Energie, 2015; Helmrich, 2017).

Surprisingly, the majority of German companies do not yet have a digitalisation strategy (Gelowicz, 2018) and only a quarter have an advanced digitalisation state of their vertical and horizontal value creation chains (Budak et al., 2018). Studies into reasons why I4.0 is not implemented a faster rate (see figure 2) reveal that German SME in particular shy away from the extensive investments into technology and personnel (Ernst & Young, 2017) and are more concerned about the costly complexity of the tasks and data security issues than larger organisations. SME have limited available resources and also have to address integration of their legacy equipment into I4.0 scenarios (Bundesministerium für Wirtschaft und Energie, 2015).

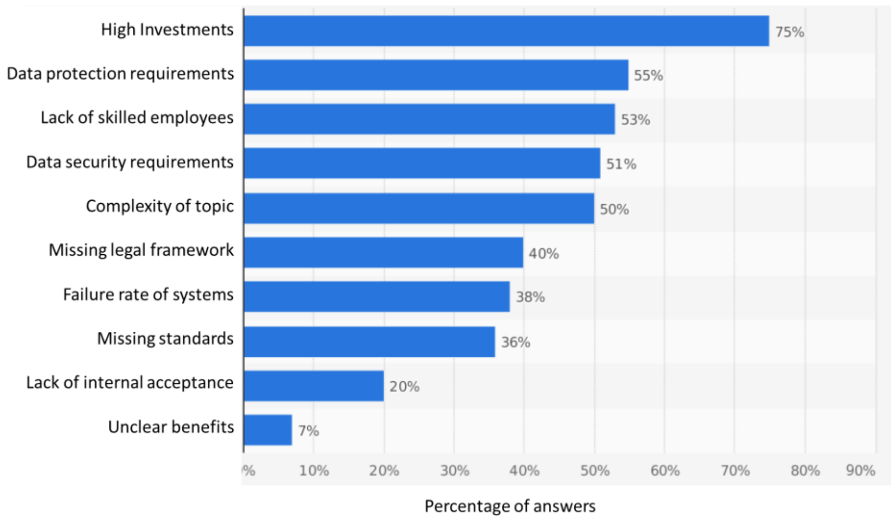

Figure 2: Empediments to I4.0 4.0 for German manufacturers (Bitkom Research, 2018)

So what are the success factors for I4.0 and what lessons can be learned from German industry? The first lesson is about *customer focus and service-orientated business models*. Companies need to satisfy vastly heterogeneous customer needs while balancing the trade-off in realizing scale effects along the value chain through standardisation and mass production. An efficient implementation of I4.0 supports the move towards mass customization that focuses on the production of personalized mass products, mostly through flexible processes, modularized product design and integration between supply chain members along the value chain. Otherwise high-wage countries such as Germany cannot compensate their inferior labour cost structure when barriers to entry diminish for new competitors (Brettel et al., 2014; Helmrich, 2017) and boundaries between producers, suppliers and customer become increasingly blurry (Ernst & Young, 2016). In addition, new businesses emerge that complement the traditional sale of machinery and products with smart services such as predictive maintenance (Goschy & Rohrbach, 2017).

The second lesson concerns the *design of collaborative production and supply networks*. It is vital to accommodate the strategic planning level decisions of shifting added-value creation from one factory or company towards integrated production and supply networks with an ensuing complexity of products and processes. This involves the design of the aggregated flows of materials and products among suppliers and facilities not only from a procurement point of view, but also from a distributional perspective towards customers (Altmann, 2015). Networks offer a number of advantages: risk sharing, pooling of resources, expansion of market opportunities, and overall a more agile adaptation to volatile markets and shortened product lifecycles. However, the decoupling and spatial separation of production processes comes with high costs for coordination, synchronization, and cross-company data sharing and integration (Brettel et al., 2014; Lödding et al., 2017). Furthermore, different mentalities towards information and cost-sharing as well as opportunistic behaviour can deteriorate or even destroy the benefits of the collaboration network. Therefore, adequate control measures across all production- and supply-related actors need to be operationalized by formal safeguards to manage the complexity of the networks (Dietl et al., 2009).

The third lesson lies in *Data Management*. The success of I4.0 scenarios depends on the availability, adequate processing and distribution of the necessary information for the efficient steering of the collaboration networks. These data come from ERP-systems, product sensors, machine data as well as production information (e.g. runtime, capacity usage, order status) across all network partners. The value, however, does not lie in collecting the data, but in amalgamating and analysing it for the entire network in order to propose the best possible combination of network partners for a particular customer request. Likewise powerful analyses are needed for real-time predictions, e.g. for predictive maintenance or system status, to provide smart services to the customers. However, algorithmic challenges inhibit data exploitation, in particular in settings with polynomially or exponentially growing run-time.

Finally, it has to be noted that the major challenge of I4.0 is not the technology, but the *management* of the digital transformation process including the design of supply networks (Mason & Wagner, 2005). Managers underestimate the speed of the transformation and as a result necessary organisational structures and cultures are not being implemented with adequate speed (Goschy & Rohrbach, 2017). Even more seriously, the majority of German manufacturing companies has not even started to develop an I4.0 roadmap that is grounded in a cross-functional and agile digitalization strategy (Sniderman et al., 2016). Neither, are the benefits of collaboration networks explored in depth as are innovative business models (Bundesministerium für Wirtschaft und Energie, 2015; (Goschy & Rohrbach, 2017); Plattform Industrie 4.0, 2016).

Case Study: Industrie 4.0 in automobile manufacturing

The automobile industry is among the most important industrial sectors in Germany and hence has a strong influence on overall economic development. Its competitive environment is characterised by increasing dynamics and volatility combined with a market saturation in voluminous core markets (USA, Europe or Japan) as well as an intensifying price competition. Furthermore, the industry experiences shorter product life cycles and growing customer demand for individualised products (Gölzer & Fritzsche, 2017; Hung Vo, 2016) which leads to a high diversification of products through variants and customer-specific fittings. Manufacturers have addressed these challenges by reducing vertical integration and shifting activities to their suppliers (Reinhart et al., 2017). Consequently, both product and process complexity have vastly expanded within the automotive industry (Hung Vo, 2016). In addition, market developments such as shared-ride and car sharing models have demonstrated the disruptive power of digital business models. This setting calls for I4.0 scenarios and it is hardly surprising that the automotive industry is one of the forerunners. Almost all German companies in this industry already work with smart manufacturing concepts or explore digital additions to their business models (Goschy & Rohrbach, 2017).

Current car buyers expect they can configure all possible features of their automobile ranging from colour to seats, engines, tyres and audio-visual equipment. Digitisation will soon allow customers to change the colour of their vehicle up to the moment the car body enters the paint shop. Digital features will change future user experiences with the car reminding the driver that the next inspection is due based on actual wear and tear or the manufacturer being able to keep in touch via personalized audio-visual messaging. Sensors will provide manufacturers with extensive data sets on actual car usages and performance which can analysed to improve future car design (Helmrich, 2017). Data analytics also provides entirely new business models around upstream data usage, offering paid services during the product-lifetime. This is particularly interesting for the high-volume manufacturers that have lower profit margins in the traditional point of sales model (KPMG, 2018).

Production systems at German automobile manufacturers are being redesigned to handle the complexity induced by the market (Dunckern, 2017). Other requirements are to further improve productivity of production (e.g. costs, time, quality), but also an increased flexibility to produce more variants and to address the ensuing complexity (Reinhart et al., 2017). However, it is important to note that German automobile manufacturers do not expect a batch size of 1 as propagated by I4.0 purists. Manufacturers perceive it as either irrelevant or not feasible for implementation in their current market environments (Goschy & Rohrbach, 2017). They also have no intention of deviating from the focal firm concept, contrary to what is propagated for I4.0.

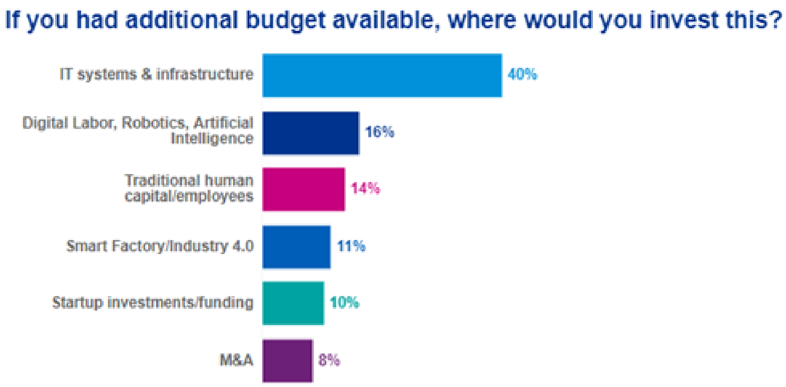

Figure 3: Investment in the automotive industries (KPMG, 2018, p. 8)

All I4.0 enablers and technologies such as IoT, CPS, artificial intelligence, human-robot-collaboration, virtual and augmented reality, driverless transport systems, RFID, additive manufacturing or drones have or are about to become standards in German automobile production (Brettel et al., 2014). IoT in particular is regarded as an important enabler for information sharing across participants in collaboration networks (Tietze et al, 2017). Every new car is now a part of the IoT and vehicles are communicating with each other, and sending and receiving data via cloud. The technology supports, for example, lane compliance, parallel parking or setting insurance premiums according to driver capability.

Looking ahead it is interesting to note that a surprisingly high share of automobile executives (40%) would invest into IT systems & infrastructure rather I4.0. However, this could also be an indicator that executives perceive a homogenous IT as necessary prerequisite for I4.0 can be fully implemented (KPMG, 2018).

Conclusion

The results of the meta-study show that the implementation of the Industry 4.0 can vary depending on the industry and the size of the company. Large automobile manufacturers are fairly advanced in collaborating with suppliers, yet real-time routines for assessing and integrating actors into the supply network are still underdeveloped. Beyond that, SME also struggle considerably with understanding the implications for their business models. Fully adaptive supply network design consequently still lags behind the original propositions as do real-time data exploitations. Most notably, many existing studies do not or only superficially address the business model level, thereby neglecting the question of how the considerable costs of realizing Industry 4.0 can be recouped from increased sales.

This paper adds knowledge on designing supply networks and operations strategy for Industry 4.0 settings when moving away from focal firms to more decentralized procedures, including competitive challenges in and between networks. Current findings indicate, however, that executives do not regard full decentralisation of decision making as an option, but prefer to manage networks in focal position for the relevant segments of their supply chains.

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