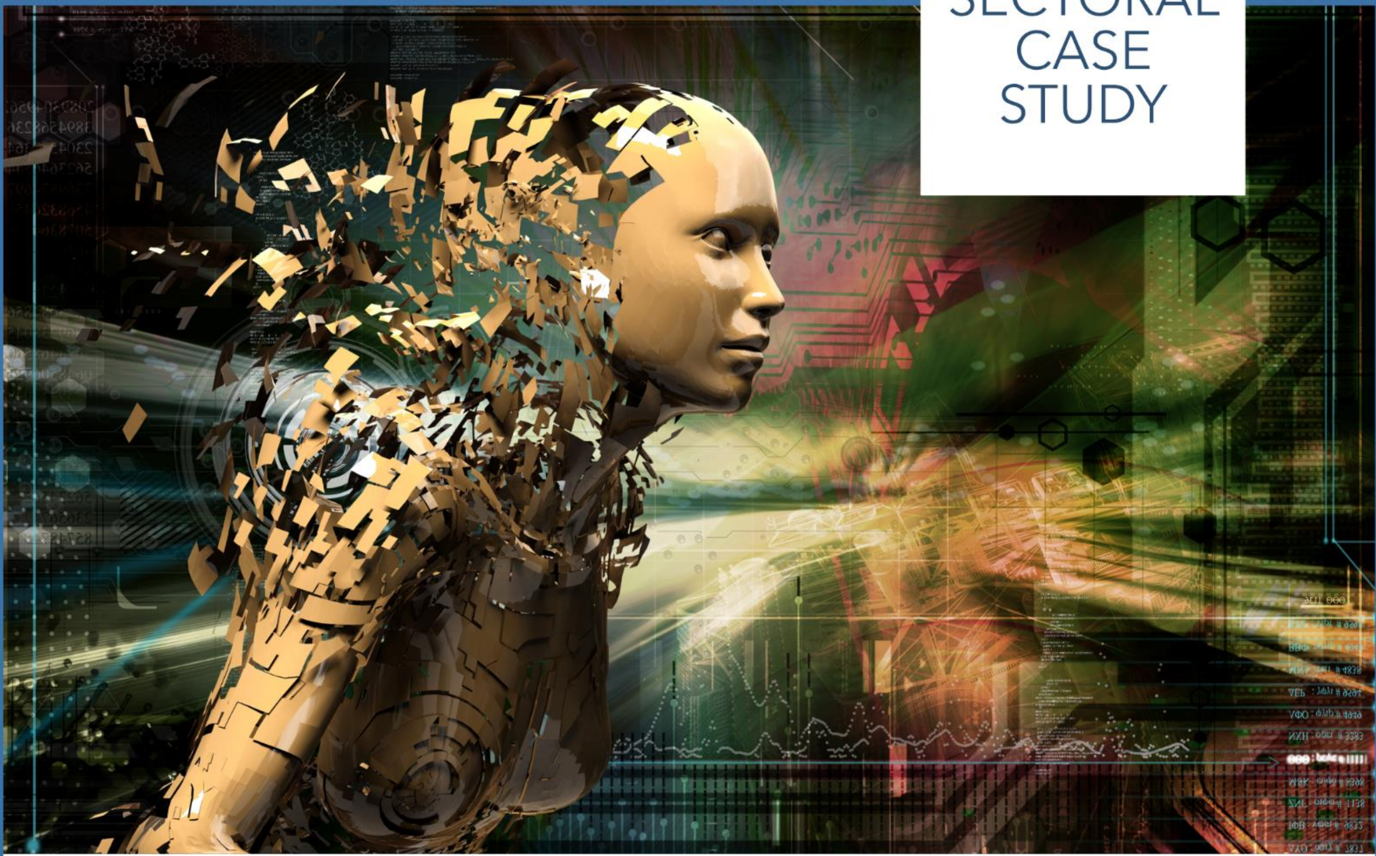
SECTORAL CASE STUDY



The digital transformation of the automotive supply chain – an empirical analysis with evidence from Germany and China

Case study contribution to the OECD TIP Digital and Open Innovation project

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The digital transformation of the automotive supply chain – an empirical analysis with evidence from Germany and China: Case study contribution to the OECD TIP Digital and Open Innovation project

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Executive summary

The automotive sector is one of the most important industries for many industrialized countries. With over 20,000 parts in one vehicle sourced from thousands of suppliers globally, the automotive supply chain is also among the most complex in the world. Major technology-driven trends such as autonomous driving, electrification, car connectivity and multimodality are predicted to lead to the biggest transformation of the industry since the invention of the car in 1885.

Industry 4.0 stands for a new level of organization and control of the entire value creation chain during the life cycle of products. A vision of this fourth industrial revolution is that machines and production systems can control themselves, based on data collected from any device. The most important characteristic feature of Industry 4.0 is digitalization. In companies, digitalization is changing business and operating models and transforms supply chains for improved reliability, agility and effectiveness.

In this context, we completed a research project about the digital transformation of the automotive industry supply chain. Semi-structured interviews were conducted with 15 experts in China and 12 in Germany in 2017 and 2018. These experts were employed in leading purchasing, production, and logistics functions at OEM, Tier 1 and Tier 2 suppliers so that comprehensive insights along the whole supply chain could be gathered.

Seven key technologies were investigated.

- Internet of things, where objects can communicate their physical context information, such as location, status or history, to the internet.
- Automated Guided Vehicles, fixed-area means of conveyance with their own drive, which are automatically steered and driven without direct contact, mainly used to tow and/or carry raw materials inside plants and warehouses.
- Cloud computing, a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort.
- Big Data Analytics, which refers to datasets characterized by large volume, velocity, variety and veracity as well as data analytics (also known as business intelligence).
- Robotics, machines capable of automatically carrying out a complex series of movements.
- Blockchain, an open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way.
- Mobile services and technologies, all types of portable tools and resources that are available to be carried around, promoting remote and local multipersonal communication and connection to the Internet

Technology adoption varies across actors in the automotive industry supply chain mainly based on companies' size. Multinational enterprises drive digitalization forward as they have an increased awareness about the opportunities of the digital transformation, already have certain infrastructure and employees with the right skills in place and can afford to experiment with new technologies. Small and medium sized companies perceive less

benefits of the digital transformation – or even see them critically – and have less resources available.

With a digital supply chain and the resulting closer cooperation, material lead times can be reduced, replenishment techniques streamlined, inventory planning improved and visibility increased. However, it is still a long way to full implementation of the systems and to a shift in behavioural patterns. Companies keep focusing on traditional supplier selection criteria such as cost, quality and delivery. However, some started to provide trainings in the area of Industry 4.0 to their suppliers.

To speed up innovation, automotive companies test alternative internal innovation processes. They encourage experiments, use agile development methods or change their organizational structure.

The digital transformation requires also a shift in the workforces' competences. Employees need to have the skills to understand data sets and draw conclusions out of them as well as possess interpersonal cooperation competence to succeed in an increasingly interconnected business world with people moving between different roles and projects.

Automotive companies not only adjust innovation processes internally, but also experiment with new collaboration patterns with other actors. They find creative ways to partner up with start-ups and their downstream supply chain partners.

Key challenges for digital innovation include standardization, data security and employees' skills.

- Standardization is considered a prerequisite for the digital transformation; however today various competing standards are common. In addition, standards often lack behind latest industry developments or own standards are created by OEMs and forced on their suppliers.
- Without ensured data security, companies do not believe in the broad application of new technologies. With stronger interconnection, data security must also be considered across the whole supply chain. Companies therefore store data on own servers in countries with a supportive regulatory framework, use firewalls and systems without internet access.
- Working environments will change swiftly and the number of required staffs might decline through the digital transformation. Some companies proactively adjust to the changing needs by adjusting hiring processes and invest in advanced training approaches. Others do not adopt to these changes and are at risk of falling behind their competition.

To address these issues and support digital innovation in the automotive industry, policy makers could consider following recommendations.

- <u>Standardization.</u> Fund standardization bodies, support international cooperation of standardization bodies and develop free data conversion tools
- <u>Data Security.</u> Develop data security recommendations and pass international anti-cybercrime laws
- <u>Employees' skills</u>. Enhance schooling as well as support continuous education

Introduction

For many industrialized countries, the automotive sector is one of the most important industries. In 2017, some 73.5m passenger cars and 24m commercial vehicles were produced globally, an increase of 2.36% compared to 2016. China is the largest manufacturing country with 29m, followed by the USA with 11.2m, Japan with 9.7m and Germany with 5.6m vehicles (International Organization of Motor Vehicle Manufacturers, 2017). Suppliers are a major driver of innovation and account for 60-70% of the value added of the manufacturing costs of a new car (Scannell, Vickery, & Droge, 2000). With each vehicle containing over 20,000 parts, typically sourced from thousands of suppliers from all around the globe, the automotive industry's supply chain is among the most complex in the world. While automotive sales are still growing, especially driven by China, the sector is on the verge to undergo its biggest transformation since the invention of the car in 1885. Autonomous driving, electrification, car connectivity and multimodality are the four main technology-driven trends that are predicted to disrupt the industry within the next decades (Kaas, Mohr, & Gao, 2016).

Industrial processes were improved for centuries, but according to Rifkin, only when transportation, communication and energy are redesigned simultaneously, a new industrial revolution can begin (Rifkin, 2014). The first revolution at the end of the 18th century began with the introduction of mechanical production facilities powered by water and steam. Later, the second revolution at the beginning of the 20th century began with the introduction of the division of labour and mass production powered by electrical energy. The third revolution in the 1970s began then with the introduction of electronics and IT for a further automation of the production. Today, the fourth industrial revolution is based on cyber-physical-systems (Bauer & Horváth, 2015). The vision is that machines and production systems can control themselves, based on data collected from any device (Sendler, 2017b).

This fourth industrial revolution, or Industry 4.0, stands for a new level of organization and control of the entire value creation chain during the life cycle of products. This cycle is oriented towards increasingly individualized customer demands and stretches from the concept, to the order, to development and manufacture, to the delivery of a product to the end user, right up to the recycling process, including the associated services (Bitkom, VDMA, & ZVEI, 2015; Sendler, 2017b). The most important characteristic feature, that also enables other characterizing features such as transparency or network-collaboration and socializing of products and processes, is digitalization (Pfohl, Yahsi, & Kuznaz, 2015)

Digitalization refers to the structuring of many and diverse domains of social life around digital communication and media infrastructures (Brennen & Kreiss, 2014). The wide-ranging effects of digitalization can be understood by noting the convergence effect it causes. Communication infrastructure, devices, functions and markets each converge from separate to one. A smartphone consolidates functions of former devices such as a camera, calculator or computer, offers services that were separated before and disrupts once distinct industry sectors like the telecommunication, the media and the information industry (Brennen & Kreiss, 2014).

Within a corporate setting, digitalization is changing business and operating models and transforms supply chains. With information ubiquitous available, supply chains can become digital. Such supply chains can enable superior collaboration and communication across digital platforms, resulting in improved reliability, agility and effectiveness (Raab & Griffin-Cryan, 2011).

In this context we conducted a research project about the digital transformation of the automotive industry supply chain. Two regions are particularly relevant when investigating this field: Germany and China.

The German automotive industry is worldwide recognized and known for its innovativeness, reliability, safety, and design. Accounting for 20% of Germany's industry revenue, it is the country's largest industry sector, generating a turnover of 423bn EUR (Germany Trade & Invest, 2018). Germany is home to three of the ten most valuable automotive OEMs and 19 of the 100 biggest automotive suppliers that support the industry's market leading position (Duggan, 2018; Automotive News, 2018). Germany is leading the fourth industrial revolution and coined the term "Industry 4.0". In 2011 the government launched a working group to clarify the requirements for a successful start into the fourth industrial age and to develop policy recommendations. After this group handed over its report, in 2013 three associations concluded a cooperation agreement to establish the "Plattform Industrie 4.0", an ideal thematic cooperation. This platform was gradually expanded with more actors from companies, associations, unions, science and politics in order to align all relevant stakeholders in the country ("Plattform Industrie 4.0 - Plattform Industrie 4.0," 2018).

China is by far the largest automotive market and vehicle producer, exceeding the production of Europe or the United States and Japan combined (International Organization of Motor Vehicle Manufacturers, 2017). Starting from the country's opening in the 1980s, foreign vehicle makers set up joint ventures with Chinese enterprises and supported the development of the local industry. Together with their suppliers, they created a strong automotive supply chain that today serves the domestic and increasingly the overseas market (Saranga, Schotter, & Mudambi, 2018). With its program "Made in China 2025", introduced in 2015 as part of a government action plan, China plans to develop from a manufacturing giant to the leading manufacturing power. Along the five guidelines "innovation-driven manufacturing", "prioritization of quality", "support of green development", "structure optimization within the Chinese industry" and "human talent orientation", ten defined key sectors are chosen to equip their plants with new technologies to ensure high quality, efficiency, and innovativeness (Sendler, 2017a).

As our aim was to investigate a topic that requires deep knowledge and understanding, we chose to conduct semi-structured interviews with experts. This method is a qualitative, empirical research approach that aims to describe and comprehend a topic. The interviews followed an interview guideline to ensure that certain topics are covered, and sufficient information is generated, while some flexibility for the interviewers remained (Gläser & Laudel, 2010).

We collected assessments from 15 experts in China, mainly in the Yangtze river delta, and 12 in Germany during the period of 2017 and 2018. These experts were employed in leading purchasing, production, and logistics functions at OEM, Tier 1 and Tier 2 suppliers. Therefore, we could ensure comprehensive insights along the whole supply chain.

1. Digital transformation of the automotive industry supply chain

1.1. What are the digital technologies shaping the digital transformation in the automotive supply chain? What are the main applications of these technologies in the automotive industry?

A multitude of interrelated technologies are discussed in the context of the fourth industrial revolution. Based on the literature review of Pfohl et. al who identified 43 relevant and contributing technologies and concepts, we selected the particularly relevant ones for the digital transformation of the supply chain with a high practical relevance to the automotive industry. To account for latest developments, recently identified technologies were additionally added (Pfohl et al., 2015; Tjahjono, Esplugues, Ares, & Pelaez, 2017; Bechtold, Kern, Lauenstein, & Bernhofer, 2017).

Internet of things

Internet of things (IoT) refers to the networked interconnection of everyday objects which will lead to a highly distributed network of devices (Xia, Yang, Wang, & Vinel, 2012). Objects can communicate their physical context information, such as location, status or history, to the internet – a transcendence of the barriers of physical and digital world (Schlick, Stephan, Loskyll, & Lappe, 2014). This would allow them to understand their surroundings, interact with people and make decisions. Some of the underlying technologies such as RFID, NFC or Sensor Networks, are not a novelty and IoT could therefore be considered an evolution rather than a revolution. However, with the fourth industrial revolution the technology experiences a revival with an expanded usage in number, types of devices and interconnectivity (Whitmore, Agarwal, & Da Xu, 2015; Deutsche Messe, 2016).

IoT was rolled out just a few years ago at a Tier 1 supplier but is already considered indispensable. RFID is implemented in pallets that carry the products and RFID gates are set up at production lines to ensure clear identification. Every movement is registered and once a pallet with a product arrives at a production line it signals the required next manufacturing process. If the process was not finished correctly or a part is defective, the pallet is sent to a dedicated station where operators receive automatically information about what must be reworked before the part can go back to the regular production flow.

The OEM Volkswagen employs this technology to monitor special load carriers and returnable packages across the supply chain. The arrival of component containers at dedicated points from the incoming goods area to production is tracked from suppliers to its own plants and vice versa. Such end-to-end visibility makes it easy to trace parts and serves as base for further optimization of logistics flows (Deutsche Messe, 2016).

A Tier 1 supplier uses IoT technology to manage interfaces. Kanban boxes for material replenishment are equipped with sensors. Once empty and sent back to the warehouse, they transmit a signal which will automatically create a demand order at a supplier. The next day a new delivery from the respective supplier will then provide the need material – inside new Kanban boxes.

Automated Guided Vehicles

Automated Guided Vehicles (AGVs) are fixed-area means of conveyance with their own drive, which are automatically steered and driven without direct contact. They are mainly used to tow and/or carry raw materials inside plants and warehouses, where they navigate either along physical or magnetic guidelines, by laser or with satellite navigation (Ullrich, 2015). AGVs are a key element of the factory of the future and already today several companies implemented solutions to support their internal transportation flows.

The OEM Daimler uses AGVs to connect various production lines flexibly. Vehicle bodies are loaded at the end of one production line and easily transported to another one. This replaced transport stations which were permanently installed and made modifications costly and time-consuming (Daimler AG, 2015).

In its Ingolstadt plant, the OEM Audi increases the efficiency of its warehouse operations by employing this technology. Workers don't need to spend time to walk through picking bays and to pick materials, but instead AGVs transport the required shelves directly to them. This application not only increased picking speed and efficiency, but also reduced the space needed for aisles between shelves (Audi AG, 2018a, 2018b).

A Tier 2 supplier counts on AGVs to automate its regularly scheduled pick up tours to ensure the material supply (milk runs). Instead of a human driver, a driverless train is bridging the distance from the warehouse to the production lines to replenish material. Delays and material damages could be reduced and the worker freed for higher added value tasks.

Cloud computing

Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort (Mell, Grance, & Grance, 2011). The technology is highly scalable, reduces business risks and ensures easy access so information can be shared in a convenient way (Zhang, Cheng, & Boutaba, 2010). Not only because the connected car will be the number one connected application in the world, producing 350 MB of data per second by 2020, many Cloud computing use cases are conceivable in the automotive industry (RapidScale, 2016).

Bosch as world's largest Tier 1 supplier set up its own cloud to generate learnings and build up own cloud know-how and competence. Although open to other companies, this cloud stays internally to ensure independence, especially as the supplier considers the risk that other cloud companies could become competitors in related technologies (Klostermeier, 2018).

Volkswagen set up its own private cloud, too. It should provide applications for customers, suppliers, sales organizations and internal operations. With this approach VW goes beyond their competitors that purely focus on vehicle customers, by also integrating data from IoT devices, storing them as big data and analyzing them via AI (Weiss, 2016).

A different approach was chosen by a Tier 1 supplier. It uses cloud computing to provide relevant data to technical engineers that conduct maintenance work at customer sites. Traditionally there is no unrestricted access to the Tier 1's existing systems, but with this solution certain non-critical information can be easily stored, retrieved and updated. This led to increased efficiency and productivity for the onsite engineers.

Big Data Analytics

Big Data refers to datasets characterized by large volume, velocity, variety and veracity (Govindan, Cheng, Mishra, & Shukla, 2018). Due to the fast development of networking, data storage, and data collection capacity, it becomes increasingly relevant for all domains and industries (Wu, Zhu, Wu, & Ding, 2014). Complementary to big data is the field of big data analytics, also known as business intelligence and analytics. By analyzing critical business data, enterprises can better understand their business and market and make timely business decisions (Chen, Chiang, & Storey, 2012).

An OEM uses Big Data Analytics dynamically to optimize its transportation network including transportation times, truck loads and routing. First pilots were also started to use predictive analytics to forecast transportation delays and set alarms in advance.

Schaeffler, a Tier 1 supplier, considers data analytics a key opportunity of the future and entered a strategic partnership with IBM. Thanks to self-learning algorithms employed on big data, the company could already achieve efficiency gains in production. For example, the accurate pairing success rate for a ball screw driver could already be increased by 13% points (Rosenfeld, 2017).

Another Tier 1 supplier implemented Big Data Analytics in large scale. Cycle times of assembly stations are collected and analyzed to derive process optimization possibilities such as line balancing or raw material relocations. This leads to optimized work flows for logistics and assembly operators which are also shared across all production facilities.

Robotics

Robots are machines capable of automatically carrying out a complex series of movements (Oxford University Press, 2018). Although seen as largely existing technology, the wider adoption e.g. in the logistics field will lead to gains significantly enough to impact the value chain. A key focus for automation is order preparation which typically represents half of the storage and handling costs (van Marwyk, 2016). Here, pick-and-place robots can increase production rates by speeding up the processes of picking parts up and placing them in new locations (RobotWorx, 2018). As pioneer in robot usage in production, the automotive industry is now actively working on employing this technology further across the supply chain.

In its Ostrava-Kopřivnice plant, the Tier 1 supplier Brose must handle material arriving from 200 suppliers in up to 60 trucks a day. To manage this high demand while remaining competitive, a largely automated material flow concept was implemented. Conveyor technology in combination with an automated high-bay warehouse ensures fast storage of over 180 heavy load containers per hour. When the material is required, the conveyor also transports the pallets either directly to production or to a depalletizing station. At the latter, a depalletizing robot provides a fully automated process which is faster and more ergonomic compared to a manual one (Mayer, 2016).

The Tier 1 supplier Continental also uses robots to handle components, but chose collaborative approach in its Rubí plant. Here, robots work collaboratively alongside humans to load and unload PCB boards. Handing over this non-value add, monotonous and repetitive task to robots lets not only focus operators on more skilled tasks but also led to a higher productivity with zero maintenance (Universal Robots, 2018).

Another Tier 1 supplier implemented robots for automated packaging and collaborative work. Positive experiences were made regarding the performance in terms of speed, ease of use and flexibility. Considering expected labor cost increases and technology cost decreases, the Tier 1 expects that more tasks will be handed over to robots in the near future.

Blockchain

A blockchain is an "open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way". Agreements, processes, tasks or payments could be stored, validated, shared and identified, protected from deletion, tampering, and revision. While blockchain is proclaimed to revolutionize businesses, redefine companies and economies, it would need technological, governance, organizational and societal barriers to fall (Iansiti & Lakhani, 2017; The Economist, 2015). Across a supply chain manifold use cases are imaginable to increase logistics process efficiency and data transparency (Kückelhaus & Chung, 2018).

Daimler joined the Blockchain in Transport Alliance (BiTA) and became a member of the associations board. This organization aims at creating blockchain standards in freight transportation. By using blockchain it predicts that capital can be freed up, transaction costs reduced, processes fastened and security and trust provided (Pickett, 2018). Daimler intends to "lead in the blockchain for transportation space", which enables automotive components to be tracked throughout the supply chain, making product recalls more precise and less costly, as well as improving maintenance records (FreightWaves, 2018).

To increase transparency and accountability of its battery raw material supply chain, the OEM BMW is piloting blockchain technology. Cobalt, a key mineral needed for electric car batteries, originates mainly from the Democratic Republic of Congo. Here, about 20% is produced by artisanal miners, operators - often children - that mine by hand under risk of human rights abuses and negative health effects (Amnesty International, 2016). BMW plans to use blockchain to ensure that in its batteries only clean cobalt is used. Clean cobalt is tagged with a barcode and its transportation legs stored immutable (Lewis, 2018).

Mobile services and technologies

Mobile devices are all types of portable tools and resources that are available to be carried around, promoting remote and local multipersonal communication and connection to the Internet (Sharples M., Arnedillo-Sánchez I., Milrad M., 2009; De Souza E Silva, 2006). Starting from providing only basic functionality in the 1970s and weighting over a kilogram, mobile devices today provide similar functionalities as personal computers, including email and web browsing, instant messaging and installable applications (apps) at the weight of under 200 grams (uSwitch, 2018). These devices typically include smartphones, tablet computers, smart glasses or smart watches (Rawassizadeh, Price, & Petre, 2014). As such devices are today an integral part of private lives, it seems obvious and advisable to also use them in supply chains (Schließmann, 2014).

A Tier 1 supplier uses digital production checklists on tablet computers. Operators just enter the production order number into their device and will then automatically see which assembly steps to conduct. Previously, checklists had to be printed out, repeatedly signed and measurement values filled into paper forms. Nowadays, the assembly steps can be clicked at and measurements directly entered into the system – a significant efficiency improvement.

To further improve process security, Volkswagen started to use smart glasses for order picking in its warehouses. Workers can easily control the devices via touch and voice controls to receive information about storage locations or part numbers. A camera inside the smart glasses is used as barcode reader to identify correctly and incorrectly picked parts, all operable hands free (Volkswagen, 2015).

In its Anderson plant, Bosch equipped line operators with smartwatches. In case any line fault occurs, a message is sent to smartphones which is then relayed via Bluetooth to all smartwatches on the line. Through vibrations on their wrist, the operators are swiftly informed that an urgent message has arrived and receive information about the exact location and the type of error. Thanks to these real time alerts operators can react to faults even before line stops occur, resulting in improved productivity and reduced downtime (Lee, 2015).

1.2. What are the main differences in digital technology adoption across actors in the automotive industry supply chain?

Technology adoption widely varies across actors in the automotive industry supply chain. Commonalities can be observed rather on a firm's size than on its tier position, although correlations between size and tier position exist when going deeper in the supply chain.

Multinational enterprises drive digitalization forward. They are typically aware about the opportunities of shifting to a digital business and possess the required resources to do so. All OEMs and large Tier suppliers in our study consider digitalization a high priority matter of strategically relevance. Most top-managers, often including board members, are actively involved in the topic and support related initiatives. Dr. Dieter Zetsche, Chairman of the Board of Management of Daimler highlights that "for Daimler, digitalization is the biggest enrichment since the invention of the automobile" (Daimler AG, 2018). Multinational enterprises also have already certain infrastructure and employees with the right skills in place and can afford to implement new technologies even if it won't necessarily lead to immediate improvements of the bottom line. For example, in its Thailand plant, a Tier 1 supplier set up an IoT enabled milk run. As it covers a distance of only a few meters and is not connected to other systems, the economic value add is surely questionable. However, such projects support local awareness, build-up of competences and valuable learning generation.

For small and medium sized companies along the supply chain the picture is more diverse. The possibility to generate new revenue streams, increase efficiency or transform business models through digital technologies is seldomly seen. Instead, many digital technologies are perceived as big cost item with little positive or even negative impact. Information about a Tier 1's sub suppliers, transparently stored in a blockchain, or the actual machine cycle- and downtimes, uploaded into a cloud, would increase transparency about the Tier 1's cost structure. Such increased transparency could be employed in shadow calculations and would give an OEM customer potentially advantages in price negotiations - a risk that SMEs in the automotive industry with cutthroat competition and shrinking profit margins might not want to take. In the past, customer's efficiency improvements were also sometimes conducted at the expense of their suppliers. For example, a Tier 1 requested its Tier 2 suppliers to transfer delivery information directly into its new system instead of letting own employees enter it. As system interfaces were commercially not justifiable for most Tier 2 suppliers, they had to hire additional staff to enter this delivery information into the Tier 1's system manually. While the Tier 1 could consequently become more digitalised and process efficient, the Tier 2 suppliers had additional cost burdens.

Small and medium sized companies also have less resources available and must manage them more cautiously. Digitalization for the sake of digitalization is seldom an option and decisions for investments in new technologies are made based on their commercial impact. For example, a Tier 2 supplier investigated a replacement of its currently used barcode-based system by IoT technology. While certain advantages were recognized through the new technology, the cost-benefit assessment for investing into the pricey infrastructure, while additionally risking interoperability issues with its sub-suppliers, was clearly negative. However, the pressure for digitalization through the customers often maintains. If this pressure in the automotive industry becomes too high, companies who are not in a position where they can withstand it need to make an entrepreneurial decision whether to build up the necessary know-how and conduct the required investments, or whether to readjust their customer portfolio and focus on other industries.

Differences in technology adoption are also visible when comparing China and Germany. The motivation for introducing new technologies in China is mainly for efficiency and cost reduction reasons, while in Germany it is for better planning and decision making, flexibility and customer satisfaction. However, due to the lower labor costs in China, the return of investment for technologies that improve the efficiency, such as AGVs, is lower than in high cost countries. Therefore, companies often prefer to pilot and mature technologies in developed countries first, before adopting them to China. Other companies try to maintain a global standard in all factories simultaneously to benefit from easier data exchange and economies of scale. One company also decided to pilot technologies first in China, as they perceive Chinese employees as “more open-minded towards changes and new apps and technologies than in Germany”. This openness towards technology is also reflected in the adoption of mobile technologies in China, such as the ubiquitous multi-purpose messaging, social media and mobile payment app WeChat. As this App is installed on almost every smartphone, including the one of truck driver’s or warehouse employees, companies in China started using it to scan and track goods or delivery documents. Another moderating factor are Chinese government initiatives and regulations. With various government initiatives that aim for “Intelligent Logistics”, the usage of IoT technologies, automated logistics facilities and equipment as well as intelligent decision supporting systems, companies are now encouraged and incentivized to adopt innovative supply chain technologies for the digital transformation (Li, 2018a). At the same time foreign companies in China are reluctant to introduce certain technology, such as cloud computing, as local regulations require data to be stored on servers located in mainland China where it is easily accessible for local authorities (Li, 2018b).

1.3. Has the digital transformation changed the role of or relationships among players in the automotive supply chain and, if so, in which ways?

With a digital supply chain, the two-way exchange of critical business information can be automated, leading to reduced material lead times, streamlined replenishment techniques, improved inventory planning and greater visibility. Closer collaboration is especially desired by supply chain managers during supply chain interruptions, but true digital collaboration requires a long term mindset change (Ben-Zeev, Sharma, & Ginodia, 2017).

Today, ERP systems as base for digital data exchange are in place in large and increasingly also in small and medium sized companies. Among others, supply chain management online platforms such as SupplyOn provide the infrastructure to manage demand processes, vendor managed inventory or Kanban approaches. Delivery schedules, delivery shipping notifications, just-in-time delivery schedules or invoice information can be shared.

However, it is still a long way to full implementation of the systems and to a shift in behavioural patterns. Companies partly request information integration from their supply chain partners already. Nevertheless, when selecting suppliers, the majority of companies focuses still almost exclusively on traditional criteria - cost, quality and delivery are more important than digitalisation. The experts believe that it might become gradually a more relevant criteria yet remain cautious regarding the benefits. A Tier 1 supplier explained that “how much can we internally save will be a key question. And if more data transparency becomes mandatory, how many and how fast can we find partners that are capable and willing to follow along?”

As suppliers represent a critical resource to an automotive company, most have a history in investing human and organizational resources to develop their supplier’s performance (Modi & Mabert, 2007). For example, the OEM Toyota supports its suppliers in implementing its production system or solve problems jointly. BMW involves suppliers early in product development, financially rewards innovations and builds trust (Karkaria, 2018). Considering the importance of the subject, some companies now start to provide trainings in the area of Industry 4.0. For instance, Bosch offers a “Industry 4.0 Solutions Module” which integrates problem mapping and showcases of lean production solutions and introduces advanced hardware and software solutions.

2. The effects of digital transformation on innovation practices in the automotive supply chain

2.1. How is digital transformation changing innovation processes within firms?

- Traditional innovation processes in the automotive industry can take 4-6 years. While this might be sufficient for the development of a car, it does not reflect the often technology driven change of speed in the automotive firms’ surroundings. Some companies realized this challenge and try to adjust their supply chain innovation by encouraging experiments, using agile development methods or changing their organizational structure.
- A Tier 1 supplier encouraged all its manufacturing sites to develop innovative ideas how to digitalize the supply chain. Plants around the world followed this call and set up various projects, from the development of own AGVs, over IoT installations to digital Kanban boards. While these technical island solutions pose new challenges for a later IT integration, it enabled the Tier 1 supplier to swiftly pilot technologies and gain experiences. Good practices are now improved, standardized and rolled out to other plants, while some projects are also pivoted.
- Bosch uses agile development methods in its “connected logistics” team to speed up innovation inside the organization. The iterative scrum approach is used to quickly develop digitalization solutions. First, logistics pain points that cause manual processes, low asset utilization or stress for logistics employees are identified. Then, together with operative logistics departments, improvement ways are identified how to capture IoT data and steer the material flow in real-time (Bosch Software Innovations GmbH, 2018). Prototypes are quickly generated, tested and based on the user feedback improved.
- To provide better digital support, Volkswagen reorganized its internal Information Technology department. The IT group was adjusted to be more closely integrated

with all business processes. VW trusts that open source products lead to most innovation. This understanding is already well developed in the IT department and should be also brought to other departments through these changes (Magee, 2017).

- The digital transformation requires also a shift in the workforces' competences. With data being more pervasive in the supply chain, employees need to have the skills to understand data sets and draw conclusions out of them. To generate economic value out of data, they must be versed in data analytics and data management techniques. Asides of this professional competence, in a more interconnected business world with people moving between different roles and projects, interpersonal cooperation competence will become ever more important. Employees have to be open-minded towards new ideas and innovations in addition to embracing changes that the digital transformation will bring.

2.2. How is digital transformation changing firms' patterns of collaboration with other actors (e.g. research institutions, other firms) for innovation?

- To tackle the Herculean task of the digital transformation in the supply chain, automotive companies not only adjust innovation processes internally, but also experiment with new collaboration patterns with other actors.
- With its "Startup Garage", BMW pioneered a new way to integrate early stage start-ups into the company. Instead of investing by purchasing equity, BMW purchases a start-up's product, service or technology and helps them to learn about the automotive industry and connects them with business development decision makers and development engineers. After validation of a start-up's technology, BMW aims to become a long-term client (BMW AG, 2018).
- A Tier 2 supplier recognized the importance of big data and started collecting data across its sites. However, the Tier 2 does not possess the internal capability to conduct advanced analytics. To tackle this challenge while optimizing the whole value chain, it decided to partner up with their customer. The company now shares for example machine data, which is then analyzed by a Tier 1 supplier and both companies jointly identify improvement potentials.
- Volkswagen also uses an innovative approach to vertically collaborate in the supply chain. The "Future Automotive Supply Tracks" (FAST) is an initiative to partner up closer with selected suppliers for implementing technical innovations more quickly than before. One of the strategic partners is IBM with which Volkswagen will share its cloud services and its AI-based technologies (Volkswagen AG, 2018a, 2018b).

2.3. What are the main opportunities and challenges for digital innovation faced by OEMs and automotive suppliers?

Asides of the high costs to implement new technologies, three key challenges can be identified.

Standardization

Standardization is considered a prerequisite for the digital transformation – as an expert stated, "without standards there will be no fourth industrial revolution".

Today, various competing standards are common in the automotive industry, typically developed by regional industry associations. Odette in Europe, VDA in Germany, AIAG in North America or JAMA in Japan to name a few. However, experts explain that there is still lot of improvement potential. Standards often lack behind latest industry developments which then encourages other players to develop own solutions. For example, while there exists a VDA standard for passive RFID tags, none exists for active tags. In addition, OEMs frequently create own standards and force them on their suppliers. Tier 1 suppliers therefore have to invest into costly interfaces or specific software to be able to integrate their systems and exchange data with their customers. A Tier 1 supplier shared a case where its customer used a certain costly software to create drawings and then shared them in a file format which was only readable by this certain software. Hence the Tier 1 had to align its software environment to accommodate to this. When the customer then soon after decided to switch to another program, the Tier 1 was expected to follow and change its Software environment again.

Data Security

Data security is of high priority to ensure competitiveness and protect company secrets. Without ensured data security, companies do not believe in the broad application of new technologies, although it is acknowledged that systems must remain flexible enough to react to changing market conditions and customer requirements. With increasing amounts of data and the advances in computing, this issue is predicted to become even more crucial in the future. As the expert of an OEM explained, “today, a 13-year-old programmer can make sophisticated analyses about the behaviour of his fellow pupils based on few data points. In such an environment it is very easy to analyse data and e.g. deduct the market situation of us.” To address this risk, companies store data on own servers in countries with a supportive regulatory framework, use firewalls and systems without internet access. In addition, data is often classified based on sensitivity and guidelines regulate where which security class must be stored. Nevertheless, companies have to manage the balancing act that certain data must be secured while other data has to be shared with supply chain partners. With stronger interconnection, data security must be considered across the whole supply chain – a break in its weakest entity leads to a security threat for the whole network.

Employees’ skills

Digitalization is predicted to significantly impact people employed in logistics. Working environments will change swiftly and the number of required staffs might decline. Companies react very differently to these upcoming changes. Some advanced OEMs and automotive suppliers practice open communication and include employees right from the idea generation step in digitalization projects. They adjust their hiring processes towards people with the right attitude and skills, which then can also support and convince other employees of the changes needed. They also invest in advanced training approaches, such as gamification, to motivate existing employees to keep up with technological changes. In addition, they train new hires right from the beginning. For example, Volkswagen offers a dual education “Robotronics Program” based on Industry 4.0 manufacturing principles in its own Volkswagen Academy. This two-year program combines vocational classroom education and paid on-the-job training and an associate degree from a local community college is awarded after completion.

Some companies, typically small companies, do not see the requirement for specific trainings and/or still follow outdated training approaches. By not adopting to changing skill requirements in a changing environment, they are at risk of falling behind their competition.

2.4. What do you think policy could do to support digital innovation in the automotive industry?

Standardization

Digitalization, industrialization and automatization requires standardized interfaces and processes. Standards not only reduce costs across various business aspects or support global market access, they are also an indicator for the future direction of technology. In this way, they become a guideline for SMEs in which technologies to invest today in order to be prepared for the future. To foster standardization as base for digital innovation in the automotive industry, policy makers could consider support in three areas:

- Fund standardization bodies. Organizations are a key to develop, coordinate and promulgate standards. Policy should provide the needed resources so that they can execute their crucial tasks faster in sync with technical developments. This becomes especially crucial for small and medium sized companies that cannot afford sending participants to standardization bodies without additional funding support.
- Support international cooperation of standardization bodies. While the degree of standardization within countries is on a comparatively high level, cross-country and cross-regional standardization is often in its infancy. Policy could facilitate a harmonization of standards by developing and supporting international cooperation platforms for standardization bodies.
- Develop free data conversion tools. When data is encoded in a different way, a translation is required to make it accessible. This data conversion from one format to another requires data conversion tools. Policy makers could back economical solutions to provide such tools by e.g. sponsoring the development and offering the resulting software for free, or supporting the open-source community that works on such software development

Data Security

Data security is a basic requirement for the digital transformation. It includes confidentiality (access only by authorized parties), integrity (modification only by authorized parties or in authorized ways) and availability (legitimate access is not prevented). Data security can only be assured when all three dimensions, people, processes and technology act together (Pfleeger & Pfleeger, 2003). Policy makers could support data security across the supply chain with the following measures:

- Develop recommendations. With clear recommendations all actors across the supply chain could easier follow in implementing needed measures. Therefore, policy should support existing platforms (e.g. enisa) or building up new platforms to develop recommendations for how to ensure data security when applying various technologies. This could include technical approaches, but also guidelines which data should be classified as how sensitive and how such classified data should be stored.
- Pass international anti-cybercrime laws. Companies might easier share data freely, if they have higher trust in a stable legal framework that is valid and enforced globally. Policy makers should therefore pass suitable laws that target cybercrime to deter parties from trying to obtain illegal access, conduct data espionage or data interference.

Employees' skills

The skillset needed for people employed in various function in supply chain management is predicted to change. In the future, analytical thinking and innovation, active learning and learning strategies as well as creativity, originality and initiative will become more important (World Economic Forum, 2018). Needed qualifications for employees include data and software skills such as data management, data science or human-machine interface related know-how (Lorenz, Küpper, Rüßmann, Heidemann, & Bause, 2016). To ensure that employees become an asset instead of a liability of the digital transformation in the automotive industry, policy makers can act in two areas.

- Enhance schooling. Similar to the US high school movement during the second industrial revolution, also the fourth industrial revolution requires unconventional ways to educate a skilled, flexible and productive workforce of the future. Policy makers should focus on enhancing schooling in a way that high school graduates acquire the skills needed to meet the changed requirements of the business world.
- Support continuous education. The digital transformation will accelerate the pace in which knowledge becomes obsolete. To support employees' competitiveness, they need to update their skills and capabilities consistently. Policy should provide incentives for companies to continuously invest in their workforce, e.g. by sponsoring training days or access to learning platforms.

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