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Digitization of the Car: Impact on Automotive Logistics

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Purpose: *The digitization of the car is advancing in the four prominent areas called CASE (Connected, Autonomous, Shared & Services, Electric). The respective changes to the product structure will further increase the complexity of automotive logistics. This paper has methodologically clustered these changes and identified the impacts on logistics.*

Methodology: *Via a systematic literature analysis, the automotive product structure has been categorized into six main clusters and subclusters. Subsequently, the anticipated changes in the product structure triggered by digitalization have been classified. In the last step, the resulting impacts and necessary developments for logistics have been deduced.*

Findings: *In the course of the digitization of the car, only very few systems and modules remain unchanged. Adaptations in the product structure can be expected to accelerate in the future. Conceptual solutions for automotive logistics are necessary. First approaches, as well as remaining gaps, have been identified.*

Originality: *Digitalization and technological trends pose new challenges on logistics not yet met by scientific literature, though practice offers first conceptual ideas. This paper is the first to methodologically and holistically identify the implications of the digitalization of the car on logistics, thus providing the basis for assessing conceptional solutions.*

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1 Challenges for the Automotive Industry

The German automotive industry is currently facing major challenges. Customer trust in German original equipment manufacturers (OEMs) has been affected by the diesel scandal and the associated diesel debate (Koch, 2018; Teichert, et al., 2020, p. 618). The trade conflict between the United States and China (Erber, 2019) also impacts on the sales of German cars: Sales in the important Asian market, for example, have fallen as China mainly imports German cars which have been produced in the United States (Frankfurter Allgemeine Zeitung, 2018).

Right in the middle, the German automotive industry has been hit by the Corona crisis which has especially demonstrated the vulnerability of automotive production, when production came to a prompt standstill at all manufacturers. One reason for this, in addition to protecting employees and collapsing demand, has been the interruption of the global supply chains (Köllner, 2020). As it was early suspected (Buchenau, 2020; VDA, 2020), the restart of these supply chains caused major problems for many OEMs and exposed weak points, making it difficult for production to regain former volumes (Zimmermann, 2020; Speck, 2020).

Aggravating, the automotive industry has been undergoing a transformation that is unique in its over 125-year history (Christian Hochfeld, 2017). This change is primarily driven by environmental regulations and rapidly developing information technology: On the one hand, the combustion engine is step by step replaced by electric drives. On the other hand, the digital transformation of the car is gradually enabling more and more tasks to be taken over by embedded IT that were previously the responsibility of the driver. Winkelhake (2019, p. 36) calls it the "mobile data center" and an "IP address on wheels".

In the course of this digital transformation of the car, only very few systems and modules remain unchanged and adaptations in the product structure can be expected to accelerate in the future. These changes will naturally affect the automotive supply chains and it is crucial to be prepared in context of global competition. Yet, this issue has not been met sufficiently by scientific literature, though practice offers first ideas. Hence, this paper addresses the issues to identify the implications of the digitalization of the car on the supply chain and logistics and deduce necessary conceptual solutions for automotive logistics.

For this purpose, the digital transformation of the car has been analyzed in-depth (chapter 2) and the triggered changes in the product structure have been methodologically classified (chapter 3). The impacts on supply chains and logistics have been analyzed (chapter 4) and novel pathways for supply chain development have been deduced. This contribution closes with a summary and a perspective on future scientific work.

2 The Digital Transformation of the Car

Stricter regulations for emissions, lower battery costs, widespread charging stations, and increasing consumer acceptance will continue to drive the spread of electric cars, i.e., hybrid, plug-in, battery electric, and fuel cell cars in the upcoming years (Buss, et al., 2018, p. 32; Vallée, et al., 2018, p. 93; Krug and Schulze, 2020, p. 59; Statista, 2020). Current forecasts predict that by 2030, electrified cars will represent 50 percent of new cars sold (Felix Wilker, 2017). The speed of deployment will be determined by the interaction between consumer demand (driven in part by the total cost of ownership) and regulatory pressures, which will vary widely at the regional and local levels (Mosquet, et al., 2020). Acceptance rates will be especially high in developed, crowded cities with stringent regulations and consumer incentives (tax incentives, special parking, and driving privileges, discounted electricity prices, etc.) (Buss, et al., 2018, p. 30).

Furthermore, with battery costs rapidly declining over the next few years, electrified cars will become cost-competitive with conventional cars, providing the key catalyst for market penetration. Advances in charging technology, range, and awareness will further improve the customer value proposition (Mohr, et al., 2016, p. 12). Moreover, continued improvements in battery technology and respective costs will make local differences less significant (Buss, et al., 2018, p. 32; Statista, 2020). So all over the globe, electrified cars are expected to gain increasing market share over conventional cars (Buss, et al., 2018, p. 28; Kasperk, et al., 2018, pp. 143–144). But it is important to note that in addition to fully electrified cars, a large proportion of sales will still fall to hybrid-powered cars, i.e., the internal combustion engine will stay relevant beyond 2030 (Kasperk, et al., 2018, pp. 143–144). According to BMW CEO Oliver Zipse, electric, combustion, and hybrid cars will coexist on the assembly line in the future, especially as long as customer preferences have not yet been determined in full (Wimmelbücker, 2017; Riering and Johannsen, 2020). In consequence, a further diversification of automotive products is to be expected for the near future. According to Prof. Dr.-Ing. Lutz Eckstein, the number of offered, differing automotive products will continuously increase as the established segments are supplemented by new, e.g., automated shuttle cars (Reichenbach, 2017, p. 23).

Nevertheless, it is worth noting, that the digital transformation of the car does not stop at the electrification of the powertrain, but changes to the car can be observed in all areas of the product structure. Particularly due to the development of autonomous driving, which has attracted a great deal of attention in recent years (Brenner and Herrmann, 2018, p. 427), the share of electrical and electronic hardware in the components of a car has been increasing for decades and also for some years now the software share (Gärtner and Heinrich, 2018, p. 7). The integration of a wide variety of intelligent assistance systems has similarly and significantly increased the complexity of parts (Krumm, et al., 2014, 190 ff.; Kampker, et al., 2016, p. 167). Affected are the proportionate costs of electronic components, whose share is expected to rise by 50 percent until 2030 (Nikowitz, 2016, p. 184). And in addition, the electrification of the car allows the introduction of further innovative services. For example, cloud-based services are proposed as part of the car architecture to realize maintenance and software updates (Patterson, 2017, p. 32). As a positive side effect, customers may conveniently customize a car to their specific preferences via cloud service (Herchet, et al., 2015, p. 42); an important factor when it comes to the increasingly important business model of car-sharing.

In summary, subsumed under the simple term “digital transformation”, the car becomes metamorphosed into an automated, connected, and electric system. Daimler refers to this combination of developments with the expressive acronym "CASE", which stands for "Connected", "Autonomous", "Shared & Services" and "Electric" (Daimler, 2018). Although this development has been observed for years, the disruptive change in the automotive industry will continue for several years, as consumers, technology, and products still need time (Mohr, et al., 2016, p. 12). The significance of this development for the supply chain will be discussed after the induced product structure changes have been analyzed more thoroughly in the next chapter. Therefore, a systematic literature review has been performed. The digital databases ScienceDirect, Springer Link, and Google Scholar have been searched for recent publications (2013 to 2021) describing changes in the product structure of the car or the CASE megatrends.

3 Product Structure Changes driven by Digital Transformation

The product structure of a traditional car based on an internal combustion engine is characterized on the highest level by six module clusters (Figure 1), namely drive unit, powertrain, body and exterior, chassis, interior, electric and electronic (eVchain.NRW, 2014, pp. 20–22). In the following, the anticipated changes in these clusters will be discussed with special regard to a battery electric vehicle (BEV) and the autonomous car.

In the domain of the drive unit and the powertrain, no component remains unaffected in the course of the electrification of the powertrain. In the case of the drive unit, the combustion engine and fuel system, the air supply (for cooling), and the exhaust system are eliminated. Instead, an electric motor, an energy storage (in the case of the BEV, the battery pack), a thermal management for the battery, and a charging system are integrated as new systems. Changed modules comprise the engine management system, the engine cooling system, and ancillary units, with the latter being eliminated depending on the car's architecture (eVchain.NRW, 2014, p. 87; Buss, et al., 2018, pp. 28–29; Pawlikowski, et al., 2018, p. 6). Regarding the battery electric powertrain, all components, i.e., drive shafts, differential, axle drive, and prop shaft, are eliminated except for the transmission, but which changes significantly in the electrically driven car (eVchain.NRW, 2014, p. 87; Buss, et al., 2018, pp. 28–29; Pawlikowski, et al., 2018, p. 6).

Figure 1: Product Structure Clusters (cf. eVchain.NRW, 2014, pp. 20–22)

In the body and exterior domain, especially structural reinforcements are necessary due to the necessary protection of the battery pack and in consequence also the passengers from exploding batteries (Dieringa, et al., 2013, p. 257). Furthermore, as described in the patent of Daniel et al. (2015), attachment parts like the bumper become more adaptable, e.g., can change the rigidity by altering the tension of tension members based on sensor data in case of a collision. Also, a change in the bodyshell and lightweight design can be identified (Friedrich and Krishnamoorthy, 2017, pp. 14–15). Other systems and modules (front and rear body, passenger cell, frontend and rearend, doors and flaps, glazing, and lighting) remain mainly unchanged in the body and exterior domain.

In the domain of the chassis, it can be observed that all systems and modules are changing (braking system, suspension and damping, steering system, wheels and axles/suspension) in analogy to the drive unit and powertrain domain (eVchain.NRW, 2014, p. 87; Pawlikowski, et al., 2018, p. 6).

Regarding interiors, due to the lack of exhaust heat from the eliminated combustion engine, a positive temperature coefficient heating element (PTC) needs to be integrated to heat the air inside the car. Passenger protection will benefit from advancing digitalization, i.e., the development of more efficient sensor technology, through fast reacting and thus safer protection systems (Mattes, 2017, p. 278). The door system will change into a much more intelligent system, especially for cars used in car-sharing: Communication with the door system, i.e., unlocking and locking, will be realized via smartphone applications (Janasz, 2018, pp. 127–128). There are also efforts to allow for activation of advanced functionalities that relate to the door system, e.g., the DHL drop function for private cars (Daimler, 2019; Szybisty, et al., 2020, p. 470). The interior electronics, as well as the instrument cluster, will change significantly as new parameters (e.g., battery charge level, recuperation data) will have to be integrated. There is also a trend towards a central information and control unit (Ruck and Stottan, 2015, p. 24). For example, Tesla has integrated a 17-inch touchscreen display as an information and control unit into his Model S and Model X (Lambert, 2019), thereby reducing the number of parts and simplifying final assembly. The car's seating is also facing changes. There are already concepts for autonomous cars where front seats can rotate so that passengers can sit vis-a-vis when needed (Schlott, 2016, p. 10). This allows for business meetings to be relocated to autonomous cars. In autonomous cars, another area of interest is the cockpit. Developments look into a car without a steering wheel or with a retractable steering wheel (Pfeiffer, 2016; Winkelhake, 2019, p. 92). And the air-conditioning system, the trim, and acoustics as well as the lightweight design are changing mainly in the process of the electrification of the powertrain.

In the last domain of electric and electronic, the change can be identified in the field of comfort electronics. This is driven, among other things, by the increasing connectability of the car with the smartphone and other devices, allowing the car to be accessed remotely or content to be shared with the car (Winkelhake, 2018, p. 88; Möller, 2019, p. 444). Communication and entertainment will change as a result. For instance, extended entertainment (movies) and the idea of the car as an extension of office space could be supported by fully autonomous cars (Chai, et al., 2021, p. 155). Safety electronics will be driven forward by advancing digitalization. For example, predictive safety systems that can recognize hazardous situations before they occur are already under development (cf. Ji, et al., 2017). The other systems and modules already existing in the domain of electric and electronic are changing, particularly in the course of the electrification of the powertrain (onboard network and bus system, powertrain electronics, chassis electronics, and power supply). New systems and modules of high-voltage wiring, DC/DC converter/charger, DC/AC converter, and engine management will be integrated (eVchain.NRW, 2014, p. 87; Pawlikowski, et al., 2018, p. 6).

Figure 2 summarizes the identified anticipated changes in the product structure due to its digital transformation. Hereby, the focus has been especially laid on battery electric vehicles (BEV), hydrogen-powered cars will introduce further additional or modified components (Buss, et al., 2018, p. 29).

In summary, very few systems and modules remain unchanged in the process of digitizing the car. Moreover, the integration of new systems and modules and the elimination of existing ones is to be expected. The product structure will continue to change at an ever-faster pace in the future, analogous to the acceleration in the development of information technology. Especially software is used to provide a broader range of functions and services, including mobility services, enhanced safety, location-based services, in-car content, and remote diagnostics (Mohr, et al., 2016, p. 14). The discussion revealed that not only the single module or system in the product structure changes but there are new dependencies created in both the area of hardware and software compatibility of components. These changes will be defined especially by software.

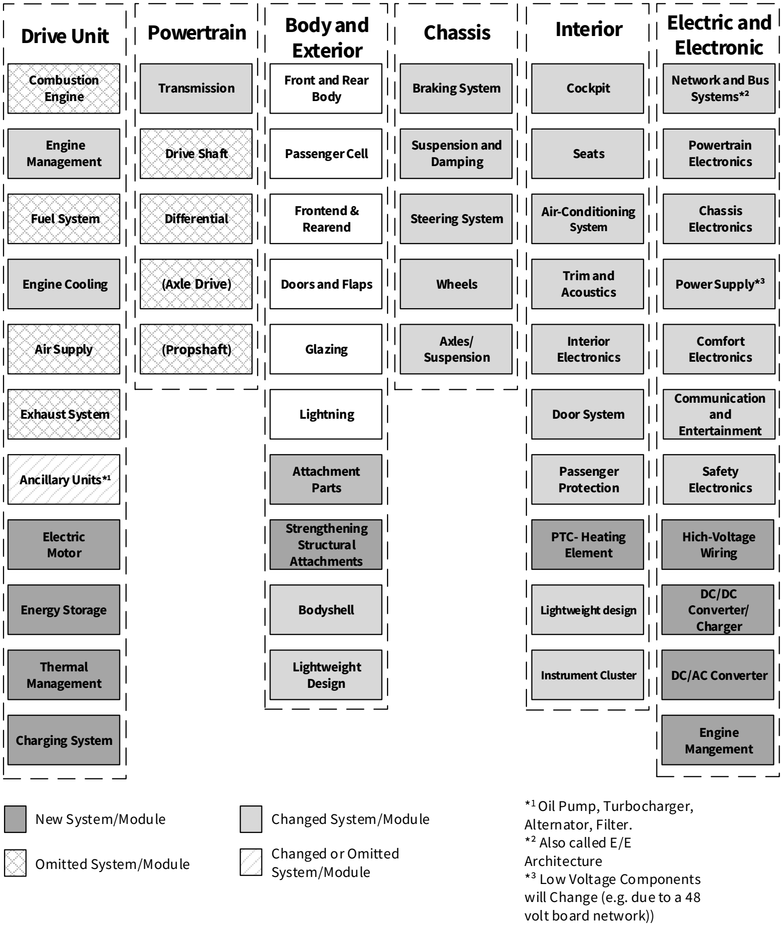

Figure 2: Changes in the Product Structure of the Car due to Digitalization

In the following section, the impacts on supply chains and logistics in particular will be discussed.

4 Impacts on Logistics

Since the beginning of industrial car production at the start of the twentieth century, the structure of the automotive supply chain has changed constantly (eVchain.NRW, 2014, p. 16). In the early days, car manufacturers mainly sourced components from suppliers and produced only a few by themselves. The sourcing strategy changed significantly with mass production from around 1915 onwards. Then, many car manufacturers have started to increasingly produce their own components and implemented a stronger vertical integration. From 1950 onwards, driven by the greater complexity of cars and the emerging customer demand for individualized products, car manufacturers reduced the depth of their own value creation. To cope with the complex logistics of high vertical integration, tasks were outsourced to selected suppliers who produced complete systems. These suppliers were integrated strongly into the development to increase the offered variety (Schonert, 2008, pp. 16–17; eVchain.NRW, 2014, p. 16). So, car manufacturers have been concentrating their efforts on the assembly of parts and modules, product marketing, coordination of suppliers, and distribution of the final product (Meißner, 2009, p. 1). This complementary shift in competencies between car manufacturers and suppliers has been manifested in the well-known automotive supplier pyramid: The OEM serves at the top of the supplier pyramid as an integrator, (left side of Figure 3; Zijm, et al., 2019, p. 90; Hoßfeld, et al., 2020, p. 428).

With the identified changes in the product structure due to the digital transformation and the resulting importance of electronic and software components, some authors predict that OEMs could be pushed into the role of the supplier for mobility services in their own supply chain, while the strategically most important role in this supply chain could be taken on by information providers (Gärtner and Heinrich, 2018, p. 7). Components that serve corporate identity and functional safety will probably continue to originate from the car manufacturer, with suppliers taking on advisory roles. Suppliers, on the other hand, will continue to supply sophisticated electrical control units (ECUs) including encapsulated systems (e.g., seat controls), low-level components (e.g., sensors), or hardware-related software, e.g., for touch controllers. Furthermore, due to their specialization and technological lead, suppliers will continue to provide certain components more efficiently than the car manufacturer (e.g., suppliers for air conditioning systems).

In this scenario, especially the system and module suppliers (today Tier-1) have a direct and increasing influence on the fulfillment of customer orders. In consequence, Buss et al. (2018, p. 63) introduce the Tier-0.5 supplier as the new supply chain stakeholder between the OEM and the Tier 1 supplier. Tier-0.5 suppliers offer even larger, more complex, and highly integrated systems. Examples include full alternative powertrains (e.g., the electric powertrain) and complete systems for the implementation of autonomous driving. Furthermore, other authors predict that OEMs will lose the top position in the supplier pyramid by 2035 and will be relegated to second place in terms of value creation to service providers like Uber and Lyft (Yole development, 2016, p. 59). These predictions of the Tier-0.5 supplier, the service provider at the top of the supplier pyramid indicate the dynamics that are already in place in the automotive supply chain (see Figure 3, middle).

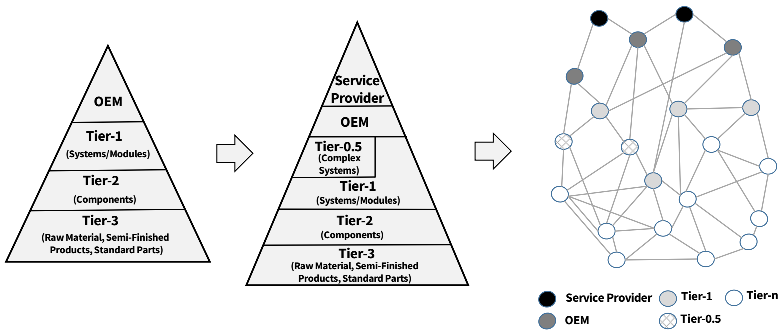

Figure 3: The Transformation of the Supplier Pyramid into a Supply Chain Network

But the transformation of the supplier pyramid might not end here. Hoßfeld et al. (2020, pp. 428–429) believe the previously inflexible product structures and also the strict existing hierarchies in the supply chain must break open. The introduction of cyber-physical systems (CPS) and the internet of things (IoT) open up new possibilities for a more real-time-oriented cooperation and collaboration in the supply chain. Only this change in the value chain structure from a strict hierarchical pyramid to a more open and flexible network will enable, among other things, more flexible responses to the fast-moving demands of the markets and potentially disruptive introduction of new car concepts and business models by competitors. The traditional rigid supplier pyramid is being dissolved and transformed into a true supply network (see Figure 3, right side).

Nevertheless, the new possibilities for cooperative collaboration might increase the already existing complexity of the supply chain. Suppliers will develop more and more systems and subsystems, which contain software drivers for car functions. As mentionend, some hardware components will be eliminated (e.g., the physical manual), and other existing hardware-based dependencies can be reduced (e.g., component wiring). The respective functionalities are taken over by software components running on domain control units (DCUs): Multi-DCUs could host radio and navigation applications within a networked cockpit (Tuzar and Schöpp, 2015, p. 30). But, the car manufacturer only needs to be involved in software development to ensure the smooth interaction of all functions. The development processes will therefore be less oriented towards components than towards functions. For the integration of these functions into the car, an electronic control unit is needed as a platform (Schuller, et al., 2017, p. 350). This, of course, is of central importance for supply chain management in general and logistics in particular, which acts as a cross-sectional function between development, procurement, production, sales, and after-sales (Fruhner, et al., 2017, p. 100). The digital transformation of the car will have an immense impact on the demand and capacity management in the supply chain: Ensuring end-to-end compatibility of the various electronic and non-electronic components becomes more and more relevant and need collaborational new approaches.

Today, platform strategies and modular concepts form the basis for the high volumes and high variation resulting from individualization but also country-specific requirements (Gärtner, 2018, p. 18). In addition, an increasing degree of modularity is expected for the embedded software modules. Over 100 ECUs are already part of a modern car and control the various mechatronic subsystems (Budaker, 2017, p. 168). And all these components are subject to constant development cycles on both the hardware and software sides. So, it is relevant not only to know which component is a hardware and/or a software component but also the respective hardware or software version and its compatibility with other components. Here, certified standards such as AUTOSAR (AUTOSAR, 2021) will be beneficial to ensure the combined functionality of components integrated into one system. But consequently, product complexity (including platform strategies and modularity) and production complexity are impacted and need to be addressed by logistics.

Especially concerning compatibility, it is necessary to take a look at innovation cycles. These are significantly shorter in the electrical industry (semiconductors, ECUs, embedded systems) than the typical car life cycle and the corresponding technical component life cycle (Krumm, et al., 2014, p. 190; Kampker, et al., 2016, p. 168). New versions of a car series are introduced every four to six years today, innovation cycles in consumer electronics (e.g., smartphones) last only about one year (Winkelhake, 2018, p. 77). The incentive for car manufacturers to upgrade electronic functions, components, or parts (and to involve respective new supply chain partners) is increasing. And additionally, after a few years of use, many electronic systems will be outdated and maybe become even obsolete. The corresponding cars can only be sold to used car customers by granting large discounts if not countered by updates on components, e.g., by integrating Apple CarPlay in an aged car (Moynihan, 2014). In sum, an accelerating change of car models within their entire life cycle can be observed. In this process, lifecycle and electronic innovations in components have to be constantly adapted to predefined structures. Managing the various innovation cycles is already a major challenge for logistics today and will become even more important with ongoing digitalization. Hence, innovation cycles and thus innovation cycle complexity represent the third area of impact on logistics.

Logistics as a cross-functional discipline has to develop the supply chain structures and collaborative processes that efficiently support planning and order management, procurement, production, and distribution under this complexity. It is also the logistics strategy that decides on the cost-efficient variety of variants, for example by preferring early or late configuration and the appropriate logistics concept. The basis for decision-making is always the anticipated sales and production volume of models and components. This information is interdependent in a variety of ways and required is an information base that subsumes all information given from engineering, sales, production, and customers and allows to derive resources and capacities required and thus to manage the supply chain. Furthermore, the mentioned dependencies need to be integrated thoroughly to support developers, assembly plants, and external service providers at any time in integrating new modules, parts, or software components quickly into an existing car structure and into the logistics processes in every phase of the product life cycle. This also applies to the supply chain of after-sales and spare parts business: to ensure compatibility with existing components, control units, interfaces, connections to energy sources, and energy consumers as well as to enable smooth handling of logistics, a complete insight into the car structure is required. It is not only the availability of components on the hardware and software side: the objective is to minimize obsolescence risks in the spare parts inventory.

Today, lack of this form of transparency does not necessarily result from the fact that the relevant data is not available, but rather from the fact that it is extremely extensive, distributed across different software systems and supply chain partners that often have no interfaces to each other and in parts inconsistent.

Consequently, to handle the digital transformation of the car, and the transformation of logistics, this collaborative information base needs to be formed from existing sources. A digital shadow of the product and supply chain needs to be build up, accessible for all stakeholders in the supply chain to support transparency and to avoid inconsistencies. Concepts like the distributed-ledger-technology (e. g. blockchain technology) might help to handle data integrity and security (cf. Guerpinar, et al., 2020, p. 157).

5 Conclusion and Future Work

The automotive industry is experiencing transformation at an unprecedented pace and will have to continue to adapt. The digitization of the car is advancing in the four prominent areas called CASE (Connected, Autonomous, Shared & Services, Electric) and adaptation in the product structure can be expected to accelerate in the future. These developments will further increase the complexity of automotive logistics and new conceptual solutions are necessary.

In this contribution, the automotive product structure has been categorized via a systematic literature analysis into six main clusters and subclusters, and anticipated changes in these clusters triggered by digitalization have been classified. It has been revealed that only very few systems and modules remain unchanged and that new dependencies arise between models, components, and parts.

Logistics as a cross-functional discipline has to efficiently provide and manage the supply chain, i.e., has to deal with the impacts on supply chain complexity, product and production complexity, and innovation cycle complexity. Therefore, automotive supply chains need to develop from the strict hierarchical structure to a more open and flexible network which allows for supply chain partners to enter and exit more freely and thus allows for more flexible responses to the fast-moving product developments, business models, and markets. The conceptual basis forms a collaborative information model, a digital shadow of the product and supply chain, maybe build upon distributed-ledger technology. Yet, for the organizational, structural, and procedural design of the supply chain and its IT support, there is still research necessary.

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