How electrified car concepts effect automotive logistics

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Abstract

Current trends, in particular the electrification of the car – as a sustainable concept within the automotive industry – cause changes of many components beside battery systems or power electronics as key components in the field of e-mobility. The analysis of scientific literature and interviews processed in cooperation with OEMs, suppliers, research institutes on characteristics of electric cars have shown radical changes in the "future car". As these changes effect the supply chain of a car, impacts concerning the logistics-relevant characteristics have to be identified.

Keywords: Car characteristics, automotive logistics, e-mobility

Introduction

Within the automotive industry, besides of the increasing integration of intelligent assistance systems to achieve a higher level of autonomous driving, e-mobility in particular as a current trend is point of interest. Though, the electric vehicle is older than the combustion engine (Kampker et al., 2013), the debate on alternative powertrains has been pushed forward in recent years. This is caused due to different factors as the limited oil stocks or stricter exhaust emission regulations (Göpfert et al., 2017). The hybrid drive – a combination of internal combustion engine and electrical components within the powertrain – is regarded as a preliminary stage on the way to a pure electric vehicle because of the limited range, longer recharge times and higher initial costs of electric vehicles (Göpfert et al., 2017; Underwood, 2014; Wallentowitz and Freialdenhoven, 2011).

The trend of e-mobility leads to radical changes in the car architecture. Beside the new components and modules (e.g. the electric powertrain or the battery system), eliminated modules (e.g. exhaust system) cause changes within the product structure of the car. Not only the car as a product is being redefined, the entire value added process must be redeveloped (Kampker et al., 2013). Today, the impacts of the changed automobile on the supply chain are not considered. Relevant impacts, e.g. the variety of models or complexity of parts, are to be identified. This situation is especially important for logistics, which acts as a cross-divisional function between technology development, procurement, production, sales and after-sales (Fruhner et al., 2017).

In addition to reduce emissions, the automotive industry pursues sustainability as a goal (Koers, 2014). Moreover, sustainability as a main driver for e-mobility is advertised with zero emission during operation, but beside to the Life Cycle Assessment (LCA) sustainability can only be reached, if all aspects of the whole product life cycle (PLC) are improved. Therefore, logistic processes as part of the PLC have to be analysed.

Methodologically a content analysis has been pursued to provide a significant overview of changes within the automobile due to the trend of e-mobility. The findings substantiate the results of interviews that have been performed in the field of the automotive industry (German OEMs, Tier 1 suppliers and universities). Interview partners have been automotive project managers, system architects, logistics manager and researchers. This analysis has been used to identify impacts on logistics. Therefore, it has been possible to deduce which trends and changes in the automotive supply chain are to be expected.

Here, the paper is structured as follows: in a first step, relevant fundamentals in context of the car and the product structures are explained. Second, the product structures of the ICEV (internal combustion engine vehicle) and electric car (battery electric vehicle - BEV) are compared. Based on this step, the relevant changes (new, changed and eliminated components and modules) as characteristics are identified. As these changes effect the supply chain of a car, impacts concerning the logistics-relevant characteristics have to be identified.

Automotive product structure and key components in the field of e-mobility

Beside to the conventional car ICEV, the automotive customer can choose from a steadily increasing amount of offered BEVs. After the car series and model has been chosen, the customer typically individualises the model by so-called options and option packages. These – sometimes – several hundred options include for example exterior, interior and security equipment, but also driver assistance systems like parking aid as a driving assistance system (eVchain.NRW, 2014; Fruhner et al., 2017). The individual configuration is used as a marketing factor for premium OEMs, but increases significantly the complexity of the product car (Fruhner et al., 2017).

Decomposition of the product car

Nowadays, beside to the amount of options a car consists of more than 30,000 parts (Shimizu, 2016). Therefore, in comparison to simple products a comprehensive product structure of the car is necessary for a holistic logistics management. According to Deng et al. (2012) a product structure is product knowledge decomposed into its elementary components from a technical view. These components can be either a physical or a non-physical artefact (service and software components) (Kissel, 2014). A similar description of a product structure is given by Schuh (2014) as a structured formation of the product and its components.

In order to obtain an appropriate overview, the car is not depicted in its entire complexity, but rather it is focused on the areas, which are subject to significant influences. Here, referring to eVchain.NRW (2014) the car will be categorised - as a product structure - in the main systems propulsion, body and exterior, chassis, interior as well as electric and electronic. Based on the findings of this contribution, e.g. (Kampker et al., 2017), the thermal management will be added as a further category. Part of the propulsion is the engine with its necessary sub-systems (e.g. exhaust system). Moreover, systems and components are assigned that transfer the generated torque onto the road (for example gear system). The second category "body and exterior" comprises all components that are used to set up a car, bodywork components and lighting. All systems and components regarding the driving comfort and driving dynamics of a vehicle are assigned to the chassis main module. A main aspect of the last category "electric and electronic" represents the onboard power supply, which is subject to significant changes.

Trends in the automotive industry

In general, the automotive industry is dealing with two major trends. One major trend is the goal of autonomous driving, which requires the development of various driver assistance systems. In the context of alternative and sustainable solutions for transportation, the electrification of the power train is considered. Vehicles, driven by an alternative drive train offer a unique advantage concerning energy efficiency, emissions reduction, reduced petroleum use and have thus become a research focus around the world. These trends and furthermore connectivity, lightweight and digitisation will have a high impact on the future of the automotive industry. (Nikowitz, 2016) They open new opportunities for designing vehicle interiors and cockpits. Furthermore, until 2030 a lot of new concept cars will be developed (Reichenbach, 2017).

In the context of improvement, extend or replacement of the combustion engine there are a few concepts that will be shortly explained. For example, in the range-extender vehicle, the BEV or the fuel cell vehicle, the electric motor is the single propulsion source (Herrmann and Rothfuss, 2015). Electric vehicle drive concepts include hybrid vehicles (parallel, HEVs), plug-in hybrid vehicles (PHEVs), serial hybrids (with range extension, REEVs), as well as BEVs and fuel cell vehicles (FCEVs) (Bauer et al., 2015).

Electrification of the car

Every concept of an electric propulsion is based on key components – battery system as an energy storage device, the electric machine, the power electronics, and a charging device (Herrmann and Rothfuss, 2015). In general, the battery system plays a significant role in the field of performance and range. Energy storage devices differ in the type of rechargeable battery, e.g. nickel-metal hydride, lithium-ion battery, or use of hydrogen in combination with the fuel cell. (Herrmann and Rothfuss, 2015)

Electric motors as electric machines can improve, extend, or even replace the combustion engine as a propulsion source (Herrmann and Rothfuss, 2015). According to Wallentowitz and Freialdenhoven (2011) they are a good choice as traction systems due to their torque characteristic. The full torque can already be applied from standstill, which in contrast to the conventional powertrain makes a clutch and a shiftable transmission obsolete. The transmission requires a maximum of two gear steps, no shift and no reverse gear because the electric motor provides it by reversing the direction of rotation (Lienkamp and Homm, 2018). In general, mainly asynchronous machines and synchronous machines with external and permanent excitation are used in electric vehicles, but nowadays the permanent magnet (pm) motors become the motor of choice for most EV applications. (eVchain.NRW, 2014; Nikowitz, 2016)

An electric drive must always obtain the required electrical energy from a suitable source of energy. This energy is converted into drive power in a highly efficient manner. As the energy storage system decisively determines both the vehicle's performance and its range, it is a key component of e-mobility (Bauer et al., 2015). The different battery alternatives vary in their gravimetric energy density (Wh/kg) and their power density (W/kg) (Herrmann and Rothfuss, 2015). Nowadays, technology based on lithium-ion batteries (Li-Ion) are used by most electric vehicle manufacturers (Yildiz et al., 2017).

The charging of electric vehicles is defined in the IEC 61851 series of standards. It defines different charging modes for alternating current (AC) and direct current (DC) charging as well as communication requirements and safety guidelines. The corresponding charging connector systems are specified in the IEC 62196 series of standards (Bauer et al., 2015). A schematic overview of available standards for Plug-in EVs charging operations are summarised in (Rubino et al., 2017). For the European market, a uniform interface system has been developed for the charging of electric cars, the so-called Type 2 connector system (Bundesregierung.de, 2014). On the vehicle side, an inlay can be offered exclusively for AC charging or – optionally – a combined inlay for AC and DC charging. In addition to the respective power contacts, the same communication and safety contacts are used for both types of charging. The standard is called Combined Charging System (CCS). In contrast to Europe, there are only single-phase network structures in the American and Japanese regions. A separate connector system, the so-called Type 1 interface, was therefore developed for these regions (Bauer et al., 2015). In addition to the CCS system, there are interfaces for fast DC charging, especially for vehicles from Japanese manufacturers, which use the CHAdeMO standard (e. g. Nissan, Mitsubishi). (Bauer et al., 2015)

In addition to the battery and the electric motor, the power electronics are one of the key technologies in electric vehicles (Kampker, 2014). The tasks of the power electronics are important regarding economy and efficiency of HEVs and BEVs. As one of the main tasks, the DC from the battery system must be inverted into AC for the electric machine and reversely in case of recuperation (Herrmann and Rothfuss, 2015). Various current converters or transformers are used for this purpose, which differ in their function (eVchain.NRW, 2014).

Comparison of ICEV and BEV product structures

In addition to the actual drive system as a change within the car, changes also refer to other components that are closely linked to the combustion engine for technical reasons (Wallentowitz and Freialdenhoven, 2011). These changes are discussed in more detail in this chapter, whereby it is separated in “new”, “eliminated” and “changed” parts.

Analysis of new components and modules within the BEV

First and most common substitution is the replacement of drive train and its corresponding components. Because of the essential changes, the onboard power supply is separated from electric/ electronic as category. For the operation of the frequently used asynchronous or synchronous machine a three-phase AC is required, which must first be generated via corresponding power electronics. In addition to controlling the motor via the power electronics, a higher-level control unit is also used. It processes the data coming from the vehicle sensors, providing functions such as slip control and stability control. (Wallentowitz and Freialdenhoven, 2011)

BEVs represent a major challenge for the thermal management regarding the interior from two perspectives: On the one hand, the elimination of the combustion engine means that there is no "free" heat source and drive unit for the air-conditioning compressor. On the other hand, the energy used for air conditioning has a noticeable effect on the battery capacity required for the drive. (Bauer et al., 2015) Since there is no mechanical drive unit for air conditioning in electric vehicles, they must be equipped with electrical heating and cooling systems. For this purpose, air or water heaters based on the PTC (Positive Temperature Coefficient), high-voltage heaters with layered technology (also known as layer heaters), fuel heaters, infrared heating elements or heat pumps as well as (supplementary) electric water pumps and air conditioning compressors can be used (Bauer et al., 2015).

A major innovation is the BEV's communication connection to the internet, which is necessary for various functions, not only for entertainment but also for security functions. For example, the connection is required for bidirectional charging, comfort functions such as pre-heating or online charge status enquiry. (Lienkamp and Homm, 2018)

Overview of eliminated components and modules

In context of the torque characteristics of the electric motor modifications of the drive train are necessitated. The maximum torque is available from standstill and then over a wide speed range. For this reason, there is no need for a manual gearbox or a clutch. Furthermore, the use of an electric motor means that the fuel tank, the fuel pump, the corresponding pipes, the injection system, the starter motor are no longer required. Moreover, an alternator is no longer required, since the electrical power supply must be ensured from other sources. (Wallentowitz and Freialdenhoven, 2011; Bauer et al., 2015)

The steering and brakes of vehicles with internal combustion engines are based on mechanical or hydraulic systems, which is a reason for changes here as well. The kinetic energy from deceleration and inertia braking cannot be used. It is converted into heat in the friction brakes and released into the environment. However, the electric motor can be used as a drive motor and as a generator when braking; the generated electrical energy can be stored in a battery (recuperation) and used as drive energy if required. It must be mentioned that only the drive wheels can be braked regenerative; a separate braking system is required to brake the vehicle (Göpfert et al., 2017).

Identification of changed components and modules

A distinction can be made between two approaches in the structure of vehicle architecture and thus in vehicle development and production design. In the "conversion design", the vehicle structure of a conventionally driven vehicle serves as a platform for integrating the electric drive train. “Purpose design", on the other hand, redevelops the overall concept of a vehicle in accordance with the requirements of e-mobility. The use of expensive lightweight materials can pay off if a smaller battery is considered for the same range. The resulting reduction in weight means that the battery volume is once again reduced, also because fewer stiffeners are required in the vehicle body. (Kampker et al., 2016)

However, the combustion engine also drives other units that are indispensable in battery-powered vehicles, such as the power steering pump, the vacuum pump for boosting the braking force, ABS, ASR and level control (Bauer et al., 2015). Steering represents a further point of changes in the course of electrification of the powertrain. The classic hydraulic steering support is based on a pump powered by the belt drive, which provides hydraulic pressure for steering assistance. In the case of electromechanical power steering, the steering movement is supported by an electric motor acting on the steering column or rack. In addition, the steering support for such a system can be adapted by software. A potential successor to electromechanical steering is the Steer-By-Wire concept. The steering is mechanically completely decoupled from the wheel. The driver's wish in the form of a steering wheel movement is detected by a sensor and sent to the corresponding actuators on the axle. Then, this is used to adjust the steering angle. (Wallentowitz and Freialdenhoven, 2011)

In summary, significantly modified components are: gearbox, wheel suspension, power transmission, air conditioning/ heating, cooling water pump, thermal insulation.

Concluding, Table 1 shows an overview of the analysed systems within a BEV. The applied evaluation is: N(ew), C(hanged) and E(liminated).

Table 1 – Overview of changes regarding BEV

	SYSTEM	**COMPONENT(S)**	***N***	***C***	***E***
PROPULSION	combustion engine				X
	(traction) electric motor		X		
	power electronics		X		
	fuel supply + exhaust system				X
	clutch + gear system				X
	(differential)				X
	noise module		X		
	auxiliary components	oil pump, turbocharger, alternator, filter[1]			X
ONBOARD POWER SUPPLY	high-voltage grid	wiring, DC converter	X		
	(traction) battery	cells, battery management system, case, charger	X		
	charging system		X		
ELECTRIC/ ELECTRONIC	motor management		X		
CHASSIS	steering			X	
	brake			X	
	wheel suspension			X	
THERMAL MANAGEMENT	air conditioning system	PTC[2] heating and cooling systems	X		
	air conditioning compressor			X	
	thermal management for battery/ electronics		X		

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[1] fuel, oil

[2] Positive Temperature Coefficient

Drivers of change and their logistics-relevant impacts

The drivetrain with internal combustion engine and transmission comprises about 2000 moving parts. In contrast, the electric drive train of the battery-powered electric vehicle, consists of only about 50 parts (Hansen and Porteck, 2017). But, the amount of embedded systems and software within the powertrain is rapidly growing. In today's ICEVs, the proportion of electrical, electronical and IT components is between 20 and 35% (dependent on the vehicle's class). In electric vehicles, this share will increase up to 70%. (Nikowitz, 2016) This leads to a fundamental technology turnaround, which requires adapted software within the powertrain. Thus, the systems are becoming very complex, power electronics and adaptive drive train technologies play an important role and will have a massive impact in the future. In addition, a "new" feature of electric cars is in the field of bodywork, which must be lighter in order to reduce power consumption and increase the range. For BEVs lightweight constructions are discussed to compensate the additional weight of the battery. For example, aluminium is used especially in the luxury segment (Lienkamp and Homm, 2018). On the one hand, as the amount of parts is an aspect of "product and production complexity", a simplification takes place. On the other hand, regarding the increase of embedded systems and software, new and changed dependencies are to be considered (for example compatibility of software versions). Thus, the product and production complexity of the car will have a large shift.

In the context of the trends in the automotive industry, also linked challenges have to be managed. As ICEVs, HEVs and BEVs will jointly determine the OEM's product range in the foreseeable future, a considerable increase in the variety of parts can be expected (Göpfert et al., 2017). This wider range will be caused by the different usage patterns regarding the mobility as well as new regulations (Kalmbach et al., 2011). In contrast to the ICEV, the degree of maturity of the electric vehicle is not known, thus there will be different lines of development in future. Initially, a large number of variants can be expected from this (Göpfert et al., 2017). Therefore, a driver for logistics – at least in the foreseeable future – will be the increase of variety of models as an impact on product and production complexity.

In the automotive industry, the classical product life cycles are seven years. With a development lead-time of three years, the technologies used during this period are ten years old at the end of their life cycle. Given the current rapid pace of technology development, such a cycle is far too long and leads to vehicle technologies often becoming obsolete very quickly. (Kampker et al., 2017) In this context, a continuous update of the vehicles, similar to software, must be enabled to improve sustainability instead of leaving them unchanged over the life cycle. Therefore, the aim of remanufacturing approaches is to maintain the update capability by means of a modular structure to enable a vehicle body made from new and used components. (Kreisköther et al., 2016) Moreover, in addition to the aspect of increasing model diversity, the importance of optimised – few and large – platforms and modules increases (Kopp et al., 2017). Hence, approaches regarding modularity and platform strategies are not new and still represent an impact within the automotive industry.

Another aspect regarding the parallel existence of conventional and electrified cars within the OEM's product range is the effort involved in selecting suppliers, triggering and monitoring order processes, which will increase. This also applies for the effort involved in determining material requirements and materials planning (Göpfert et al., 2017). By eliminating the know-how advantages of established car manufacturers in the transition to new vehicle concepts, relative young companies are able to enter the automotive market, which has been dominated by large corporations for decades. The dynamics of innovation can be increased from new manufacturers and exert pressure on established manufacturers. The early involvement of cooperation partners in the value creation process enables the direct availability of various competencies and technological know-how. Comprehensive networking and participation of different companies allows to increase joint performance and increase the efficiency of cooperation. (Kampker, 2014; Kampker et al., 2016) Concluding, due to these novel partnerships the complexity of the corresponding logistics and accordingly the automotive supply chain is increasing.

The rising electrification of vehicles will lead to a shift in the value added in the supply chain. In the ICEV-based supply chain, where 30 % of the value added is generated via the power train, the value added for a BEV is comparatively 60 %. This is mainly caused by the battery. (Pieper and Ernst, o.J.; Bierau et al., 2016) Moreover, the value added of the battery cell (raw material supply and production) is located outside of Europe. Raw materials account the main part of the costs of batteries, so cell producers tend to be commodity traders. Precisely the precursors of lithium-ion batteries, the battery cells, are manufactured by only a few companies worldwide. (Lienkamp and Homm, 2018; Göpfert et al., 2017) Beside of the battery, many components of the electric drive train – electric machines, power electronics, cables – require raw materials whose availability is limited or characterised by high demand and thus rising costs. These include copper, silver, lithium, rare earth metals and semiconductor elements. In addition, the reserves of raw materials are distributed among a few countries. (Göpfert et al., 2017) In consequence, it has an effect on sustainability in a reduction of local transports, but an increase on the global side. This may result in long delivery times and high logistics costs.

Thus, as electric cars have much less parts than combustion cars, less parts can get a defect (Vogt and bridgingIT GmbH, 2016). E-mobility eliminates all maintenance concerning the drivetrain; no oil change, no new spark plugs, timing belt or, in case of higher stress, even a new clutch or exhaust system. A further point is the brake system, which hardly shows any wear due to recuperation. Therefore, regarding this part of the OEM’s product range the maintenance and the corresponding logistics processes will be simplified.

The resulting impacts on automotive logistics are derived and summed up in Table 2. The applied evaluation is: S(implified) and (H)igher complexity.

Table 2 – Logistics-relevant impacts due to BEV

	IMPACT	**CHANGE**		**COMMENT**
		S	**H**	
PRODUCT AND PRODUCTION COMPLEXITY	variety	X		less parts
	share of electronic parts		X	compatibility of software
	model variety		X	foreseeable future
INNOVATION CYCLES	modularity	–		still present and important
	platform strategy	–		still present and important
SUPPLY CHAIN	procurement	X		less parts
			X	raw materials for e.g. batteries
			X	new suppliers
	spare parts	X		less moving parts

A reliable forecast regarding the share of electric vehicles is still difficult. This is confirmed by the answers of the respondents, which differ from five to 40 percent as a forecast for the share of EVs in 10 years. According to PwC Autofacts (2016), one in three new cars in the EU should be an electric car by 2030. Currently, 97 percent of all new vehicles in the EU still have an internal combustion engine.

Conclusions

The challenges and opportunities introduced by the e-mobility as a technological trend are not considered sufficiently as impacts for logistics. This knowledge is necessary to be able to identify the logistics-relevant impacts, thus the complexity of the BEV as an alternative “future car” can be managed. As the BEV seems to be – in comparison to the ICEV – a sustainable alternative, all areas within the product life cycle have to be analysed. Here, this research is important, as it is a starting point to analyse the complexity as a factor in the field of sustainability. Due to the low value-added degree of OEMs and the progressing globalisation, procurement as part of the LCA (Live Cycle Assessment) has an important impact on the sustainability of an electric or hybrid car. The analysis of scientific literature and interviews that has been processed in cooperation with OEMs, suppliers, research institutes on characteristics of electric cars have shown radical changes in the “future car”.

The different changes within the product structure have been analysed and structured in new, changed and obsolete car systems. Based on the results, logistics-relevant impacts for the automotive industry have been derived. Exemplarily, as the BEV has got less parts than the ICEV, but the share of electronic parts is still rising, a shift regarding the product and production complexity can be identified. Moreover, aspects like an increase of global transports (of rare raw materials) as an impact on the supply chain complexity have to be managed to obtain sustainability.

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