Impacts of the digitalised car on logistics

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Abstract

The digitisation of the car has introduced new and changed dependencies (NC-Dependencies) among components, e.g. the compatibility of hardware and software. Therefore, the current form of the product representation does not adequately document the new technical interrelations of components. A three-step approach (literature research, interviews and analysis of OEM data) has been followed to identify clusters of NC-Dependencies to examine their impact on logistics. The analysis and integration of dependencies between the components in the product representation is essential to assure their availability and in parallel to reduce the risk of obsolescence and recalls.

Keywords: Digitalised car, logistical impacts, product representation

Introduction

The value-added structure of the automotive industry has continuously changed since the beginnings of industrial automobile production at the early twentieth century (eVchain.NRW, 2014). Today, a particular challenge in the automotive industry is to satisfy customer requirements by manufacturing numerous variants in small quantities whilst simultaneously increasing cost pressure (Balsliemke, 2013).

For decades, the proportion of electronics in the components of a car has increased – and for some years, the proportion of software in the car as well (Gärtner and Heinrich, 2018). Especially due to the development of autonomous driving, which has gained broad attention during the last few years (Brenner and Herrmann, 2018), the number of automotive electrical and electronical components is rising rapidly. In particular, the integration of intelligent assistance systems (based on embedded systems) has led to a radical increase in complexity of parts and variants (Kampker et al., 2016; Krumm et al., 2014). This has also an effect on the costs of the share of electronic components, which will increase to 50% in 2030 (Nikowitz, 2016). These trends lead to an automated, connected and electric vehicle system. Daimler for example titled the combination of these current mega trends "CASE", which stands for "Connected", "Autonomous", "Shared & Services" and "Electric" (Daimler, 2018).

This digitisation of the car (assistant systems, connectivity and autonomous driving) has introduced new and changed dependencies among components – e.g. the compatibility of hardware (HW) and software (SW). Nevertheless, some components may be eliminated (e.g. the physical manual) or dependencies decreased (e.g. the physical wiring of components). It is especially challenging to ensure the continuous compatibility of the various electronical and non-electronical components. This applies in particular to logistics, which acts as a cross-divisional function between development, procurement, production, sales and after-sales (Fruhner et al., 2017).

A key for logistics processes to guarantee the availability of components is a transparent and holistic information basis. This product representation (a structured formation of the product, its components and their dependencies) has to depict all dependencies between parts, components and car features. However, the current form of the product representation applied in logistics does not adequately document the new technical interrelations of the components (Fruhner et al., 2017). Thus, these new and changed dependencies (NC-Dependencies) as well as their logistical impacts require an examination. This may reveal new concepts applicable for automotive logistics, e.g. over-the-air (OTA) updates for a higher degree of personalisation of the car shortly before the car is delivered to the customer, and may help to better cope with overproduced cars, which are often only sellable with large discounts.

This contribution presents a systematic analysis of the impacts of the digitalised car on logistics. Based on these findings, clusters of NC-Dependencies are identified and mapped to the impact areas on logistics. Therefore, an analysis of the product representation and the significance of its structure and information content for logistics has been conducted and will be presented in the next section. A three-step approach to identify NC-Dependencies of the digitalised car is following. Here, an analysis of current developments in the field of automotive has been performed, supported by interviews in the field of the automotive industry. Furthermore, the findings have been compared with data of German OEMs to extract to which degree the determined dependencies are already part of the product representation. The derivation of impact areas on logistics and the mapping with the identified clusters of NC-Dependencies follows afterwards. A summary of key insights and an outlook on further research is given at the end of this contribution.

Analysis of product representation in the field of automotive logistics

Today, a car is made up of more than 30,000 parts (Shimizu, 2016). A car's components consist of many simple parts, but nowadays automotive suppliers are also developing increasingly complex modules (Trojan, 2007). For many years, a shift in competence of the automobile manufacturer has been identified and analysed. OEMs are focusing more and more on the assembly of supplier parts and modules, product marketing, coordination of suppliers and distribution of the end product (Meissner, 2009).

The product representation has to combine all the information necessary to capture the customer's expected or realised requirements to determine the resource capacities and material items needed to satisfy customer or market demands. Generally, product representations are product knowledge that is broken down into its elementary components from a technical point of view. These components can either be physical or non-physical artefacts, e.g. services and SW components (Kissel, 2014). The next largest units are modules, as an assembly of several components or subassemblies. The modules (e.g. door, seat, cockpit, engine, roof), which may include a variety of functions (Rapp, 1999), should normally be easier to replace than each component of the module individually.

Logistics demand and capacity management requires information on the relationship between planned model volumes and option quotas on the one side and parts, i.e. material items, on the other side. This data is necessary to synchronise the market requirements with the capacities and constraints of the supply chain and production system. The relationship between the configured vehicle and the corresponding material items is described by the bill of material (BOM) (Pawlikowski et al., 2016). The compatibility of vehicle models and options for each vehicle series is described by a highly complex set of technical rules. These are necessary to specify the technical feasibility of customer selectable options and further OEM-internal technical options.

Logistics has to guarantee the availability of components and minimise obsolescence risks; dependencies between electronical and non-electronical components and the compatibility between HW and SW components have to be transparently documented in the product representations. Therefore, the logistics planner needs a comprehensive range of information. Technological trends, as the "digitisation of cars", have changed the requirements for the product representation for logistics.

Identification of new and changed dependencies

The literature research has been conducted within the English-speaking area using the digital databases of ScienceDirect, Springer and Google Scholar. In addition, identified literature in German language has also been analysed. Interviews within the automotive industry (German OEMs, Tier 1 suppliers and universities) with 14 highly qualified experts from different business areas (automotive project managers, system architects, logistics managers and professors) have been conducted. The interviews support, by providing important qualified information, the literature review. This analysis is divided into four subsections. As more and more advanced assistance systems (ADAS) are developed in cause of the digitisation, the first subsection deals with the electrical change of the car, especially ADAS and infotainment systems. The next subsection addresses new connectivity systems, in particular V2X (Vehicle-to-Everything) communication. Advanced assistant systems and connectivity enable the possibility of autonomous driving, which is core of the third subsection. Further on, the trend of “Shared & Services” might change the dependencies of the car, as it needs advanced electronical systems.

Electrical change of the car

Though the number of electronical functions within a car is increasing, the cable length must be kept short for two reasons: crosstalk between analogue and high frequency signals needs to be prevented and cable weight has to be reduced. In the interviews, Tier 1 suppliers propose domain controllers (DCs) combined with several decentralised electronic control units (ECUs) in this context. The literature review supports this statement, e.g. Karimi (2016) proposes less ECUs, but more DCs. DCs are not only considered within the infotainment segment, but moreover in centrally controlled ADAS architectures (Amsel and Stapel, 2017; Krekels and Loeffert, 2015). Advantages are reduced complexity of the assembly systems due to less part numbers (PNs), improved upgradeability and a faster and less complex electronic architecture (Wendt et al., 2015). The AUTOSAR-Standard (cf. AUTOSAR, 2017) is another important driver for DCs, as it allows an easy integration of SW modules from various partners (Rieth and Raste, 2016). The interviews support this statement and show that Tier 1 suppliers already supply SW modules to some extent independently of the HW. The advantages of these SW integration platforms are an effective handling of variants (upward integration and repartitioning), physical encapsulation of domains and the protection of know-how (Rieth and Raste, 2016). The exact version of the used HW standard is needed to ensure compatibility to possible SW components.

Another optimisation approach in the context of the electrical systems is the sensor fusion approach. For example, laser scanners may compensate the weaknesses of sensors by combination of several sensor technologies (Schrepfer et al., 2018). Moreover, fusions of modules like the interactive steering wheel may replace the central console panel (Ruck and Stottan, 2015). A more powerful overall system, a lighter vehicle or more space for further systems is resulting.

Not only the existing electronical systems will be developed further, but also new systems, which need (global) standards such as wireless inductive charging for electrical cars, are planned (Barkow et al., 2015). Concluding, the version of HW, SW and of the standard, the component is verified for, will play an important role.

Connectivity

Gartner (2015) predicts 250 million cars with wireless internet connection by 2020. Moreover, the connected car will become a part of a complex system-of-systems by connection with other smart products such as smart buildings (Albers et al., 2016). Several new applications regarding safety, traffic efficiency, infotainment and road-charging will be possible by data collection, processing and communication (Alfonso et al., 2017). The V2X communication will be a significant element of automated vehicles (Smith and Svensson, 2015). As connected systems (e.g. road signs) will constantly be added or removed, there is a need for a standardised system environment according to the survey of Albers et al. (2016). Connectivity is also a key factor for e-mobility, as the connected infotainment may provide information about the charging networks (Almeida et al., 2015). Moreover, to realise electric car sharing and electric fleets, the car has to become fully connected (Rahier et al., 2015). Industry understood the need for standards regarding connectivity and formed for example the “Fifth-Generation Automotive Association” (5GAA) with members like Audi AG, BMW Group, Daimler AG, Huawei, etc. (Uhlemann, 2017). Among other things, the association provides standards for networked automated driving functions such as location-independent access to services and intelligent traffic solutions for the “Smart City” (BMW Group, 2016). Concluding, standardisation (HW and SW) is important when it comes to connecting the vehicle either to other vehicles (V2V) or to the infrastructure (V2X).

Autonomous driving

The SAE J3016 standard is considered as the de-facto standard for autonomous driving as it brings order to different prior proposals of standardisation from NHTSA (National Highway Traffic Safety Administration) and SAE (Society of Automotive Engineers) (Villagra et al., 2018). It identifies six levels (0-5) of autonomy. Within the deployment path of private individually owned vehicles, new ADAS and technological systems will be added gradually (Smith and Svensson, 2015).

To achieve a high level of autonomy, several sensor technologies such as GPS, ultrasonic, infrared, radar, lidar, and camera systems are needed (Brenner and Herrmann, 2018). Up to date cars reach up to level 3 (conditional automation), e.g. AUDI A8 (Müller and Tappe, 2017). Vehicles reaching level 5 (full automation) are estimated for the beginning of the next decade (Bosch, 2017). In 2016, Tesla started to equip its cars with

HW capable for fully autonomous driving, whereby the SW part will be provided via OTA-updates in future – as the technology advances (Colquitt et al., 2017).

The current developments demand for a certain flexibility within the product representation of the car as it is necessary to not only update the SW, but also to update the HW within a car to counteract sale losses through outdated technologies. The interviews reveal that though HW updates are realistic, they might be limited to easily accessible components (e.g. car radios). Another mentioned solution is the automatic recognition of components at boot time. Concluding, the HW version (besides the SW version) is important when it comes to autonomous driving. Furthermore, the ability to provide OTA-updates is important for a quick reaction to technological changes.

Shared & Service

The digitalisation of the car allows the introduction of innovative services. Cloud based services as a part of the vehicle architecture are proposed to allow maintenance and SW updates (Patterson, 2017). The SW may be updated OTA, which simplifies the logistics process. As a side effect, customers may be given more possibilities to personalise the vehicle: an important factor when it comes to shared vehicles. Every customer could easily configure a vehicle to his or her special user settings by application of the customer ID via an available cloud service (Herchet et al., 2015). Nevertheless, the OEM or dealer has to manage and control patching processes to avoid unsafe configurations (Patterson, 2017). The interviews reveal how compatibility is assured today: A non-modifiable area of a microcontroller is overwritten at the end of the line with a HW version and HW variant ID. The new SW is provided with meta information for HW compatibility. A compatibility check is executed before overwriting the SW running on the ECU, which might also be used by OTA-updates in future. Tesla for example offers their customer optional updates as the "ludicrous mode", which unlocks additional performance (Gärtner, 2018; Freitag, 2016). Concluding, the possibility of OTA-updates enables new services such as personalised shared vehicles.

Findings and comparison with OEM data

The analysis revealed that especially information about different component versions is highly relevant for logistics. In addition to the version of HW or SW components, the version of the certified standard is important to ensure the functionality of all components involved in one system. Here, logistics is of utmost importance, as the right component with its correct version must be delivered to the right place at the right time. Furthermore, logistics needs to be informed whether a component is a physical or a SW component. Some HW components might be eliminated and replaced by SW components running on DCs, e.g. a connected cockpit multi-DCs might host among others radio and navigation applications (Tuzar and Schöpp, 2015). Depending on the type of component, different logistics processes are required. For example, SW components or SW adaptations are delivered OTA on the HW after production.

Summarising, the resulting clusters of NC-Dependencies have been identified as follows:

• SW Version	• SW Standard	• Possibility to update SW
• HW Version	• HW Standard	• Possibility to update HW

The product representations of two German OEMs have been analysed regarding the discussed dependencies to extract whether information about these NC-Dependencies are already contained in the product representation. The data contained all car types and models, options, parts, and rule-based dependencies (technical rules and BOM rules) that are necessary to build any car of these OEMs.

The analysis revealed, that an attribute, which indicates the updateability of the components (SW or HW), is not present in today's data. Furthermore, the version of the SW, which is running on an electronical device, is not included in the data. Whereby, the HW versions of components are partially depicted in the data when a new PN is assigned for a new HW version. The versions of the standards of components are also not depicted in today's product representation, as they had no relevance for logistics so far.

Impact areas on logistics

In the first subsection, the impact areas of the digitalised car on logistics are derived. These impact areas will be mapped to the clusters of NC-Dependencies in the second subsection.

Derivation of impact areas on logistics

According to Univ.-Prof. Dr.-Ing. Lutz Eckstein, the number of different automotive products will continuously increase as the established categories will be joined by new ones, e.g. automated shuttles (Reichenbach, 2017). OEMs may be forced into the role of a supplier in the supply chain for mobility services, while the most strategically important role in the supply chain may be occupied by information providers (Gärtner and Heinrich, 2018). The interviews revealed that especially components that reflect the corporate identity will further originate from the OEM, where suppliers will assume advisory positions. In contrast, suppliers will deliver low-level components, e.g. sensors or SW for touch controllers. There will always be suppliers who are able to supply certain products better than the OEM (e.g. climate control suppliers) due to their specialisation. Thus, the management of these suppliers will continue to constitute an important part of logistics. Today, different supply concepts (e.g. just in time or just in sequence delivery), global supplier locations, long distances, and varying material flow systems are fostering the complexity. Hence, one impact area of the identified dependencies, which is to be analysed, is “supply chain complexity”.

A shift in roles between the OEMs and their component suppliers can be identified. Nowadays, suppliers develop standardised systems and subsystems. These systems contain “SW drivers” for vehicle functions. The OEM is involved in the SW development, as the responsibility for the interaction between all functions needs to be continuously ensured. In effect, development processes changed from component orientation to function orientation. An ECU is required as a platform to integrate the functions into the car (Schuller et al., 2017). Platform strategies and modular concepts (modular systems) form the basis for the high volumes that are accompanied by many country-specific variants (Gärtner, 2018). Not only physical modules, but also a high degree of modularity can be identified within the automotive embedded SW. Standards as AUTOSAR (AUTOSAR, 2017) support this SW modularity. In consequence, “product strategies” (including platform strategies and modularity) and production complexity are impact areas on logistics.

Over 100 ECUs are part of a modern car and control the different mechatronic subsystems (Budaker, 2017). All these components are subject to constant development cycles on both the HW and SW sides. To guarantee their compatibility is essential. Nevertheless, innovation cycles in the electrical industry (semiconductors, ECUs, embedded systems) are still considerably shorter than typical vehicle life cycles and the corresponding technical component life cycles (Kampker et al., 2016; Krumm et al., 2014). While new versions of a car series are launched every three to eight years, innovation cycles of consumer electronics (e.g. smartphones) last only about one year. The incentive for OEMs to upgrade electronic functions, components or parts (and include new supply chain partners such as Apple or Google) is increasing. In effect, a continuous change of vehicle models within their life cycles may be observed. Life cycle and electronic innovations in components must be constantly adapted to given structures. Managing the different innovation cycles is already a major challenge for logistics, which will gain further importance with digitalisation. Concluding, “innovation” cycles are an impact area on logistics.

Summarising, the impact areas of NC-Dependencies on logistics have been identified as: product and production complexity, supply chain complexity and innovation cycle complexity.

Framework

The derived impact areas on logistics will be mapped to the identified clusters of NC-Dependencies in this subsection. Table 1 shows the results with the following rating applied:

• +: increasing complexity • -: decreasing complexity • ○: no impact

With a rising number of versions on SW side, production needs to handle a larger number of SW compatibilities. Therefore, the product and production complexity increases (+). In contrast, fewer HW versions result from the introduction of DCs and fusions (e.g. sensor fusions) and lead to a decrease (-) of product and production complexity. Furthermore, adaptations to the different standards may be necessary within a life cycle, which increases the product and production complexity. In contrast, standards increase compatibility, which decreases the complexity, as there are less unresolved dependencies. This leads in sum to a rating of “+/-“ for SW standards for product and production complexity. The same argumentation applies for HW standards (+/-). As the SW will be updateable in a digitalised car, the variance of SW versions will increase. Country-specific SW versions are another multiplier. However, as a smaller variety of parts has to be delivered, there is no impact (○) on product and production complexity. Updateable HW does not have an impact (○) on the product and production complexity. However, updateable HW might have an effect on the aftermarket, as cars can be individualised at the dealer.

More SW combinations will result, due to faster development of SW components compared to HW components. This leads to an increase (+) of innovation cycle complexity. The impact of HW version regarding innovation cycle complexity is not yet definitively estimable. There will be fewer ECUs or DCs within a car, but whether the computing power is high enough for a life cycle of the vehicle is inestimable. Unlike the SW version, the SW standard does not have an effect (○) on innovation cycle complexity as the standard is defined in the development process and new SW versions have to be built for new standards. The same applies to HW standards (○), although the number of updates of the HW and its standards is expected to be lower. The complexity increases (+) due to updateable SW, as there will be more and more different SW versions, which must be compatible with each other. In order to remain competitive as a supplier, innovation cycles for HW may shorten due to updateable HW. Thus, an increase (+) of the innovation cycle complexity is expected.

The supply chain for physical parts remains the same or even fewer parts have to be supplied, as the parts will be customisable by SW. This leads to a rating of “○/-“. DCs instead of an ECU for each function lead to fewer modules and PNs within the supply chain. As a result, the supply chain complexity will decrease (-) in terms of HW versions. Standards increase the compatibility, i.e. there are fewer unresolved dependencies. Within a model cycle, however, adjustments to the different standards may be necessary. This results in a rating of “+/-“ for the supply chain complexity for SW and HW standards.

Lesser different physical parts are needed when the SW defines the part, and therefore, the supply chain complexity decreases (-). Because last adjustments can still be made at the dealer with updateable HW, the supply chain complexity also decreases (-).

Table 1 – Mapping of the Clusters of NC-Dependencies to the derived impact areas

	Product and Production Complexity	Innovation Cycle complexity	Supply Chain Complexity
SW Version	+	+	○/-
HW Version	-		-
SW Standards	+/-	○	+/-
HW Standards	+/-	○	+/-
Updateable SW	○	+	-
Updateable HW	○	+	-

Conclusions

Today, the challenges and opportunities introduced by the trend of the digitisation of the car are not considered sufficiently for (the product representation for) logistics. Consequently, processes are not always under total control: Customers become involuntary beta tester, as in the case of the recent recall airbags (O'Malley, 2016). The results are huge unplanned costs and a considerable loss of image. The analysis and integration of new and changed dependencies between the components in the product representation is essential to assure availability of the components and in parallel to reduce the risk of obsolescence. In particular, it is important to manage the dependencies of technical and electronical components and to obtain a transparent view of the compatibility between HW and SW components.

This research is an important starting point as it specifies the new and changed logistics-relevant impacts and extracts clusters of NC-Dependencies of the digitalised car to be considered in the product representation. Nonetheless, there are factors that are unclear today. An estimation of the change of market complexity caused by the digitalised vehicle cannot be given today, due to the lack of information as the first generation of digitalised vehicles is just arriving at the market. The current trends in the automotive industry might contribute significantly to market complexity as, for example, different laws are applied (Färber, 2016), which affect the allowed assistant systems sold on a specific market. Furthermore, as navigation systems, radios, etc. have already been removed as a part and will only be an APP, the PN for the HW parts are omitted. Now, it is undefined whether the APP will be assigned a PN for logistics in the future.

The insights of this paper will be used for a proposal of an integration of the identified changes into the product representation of German OEMs.

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