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Component classification for modularization of passenger vehicles for enabling lifetime extension within a circular economy

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ABSTRACT: Extending the lifetime of products is one objective of a Circular Economy. The lifetime of a vehicle is limited not only by wear, but also by declining customer satisfaction. Customer satisfaction is related to the different types of quality. Components aim for different types of quality. That is why modularization is seen as a possible enabler to facilitate both durability and adaptability in the vehicle structure. Additionally, extending their lifetime integrates passenger vehicles into a Circular Economy. This paper aims to define classes of components to support the development of a modular structure for passenger vehicles that is suitable for a Circular Economy. It provides four classes based on the relevance of components to customer satisfaction and their expected lifetime. This enables the targeted development of R-strategies for components.

KEYWORDS: circular economy, product architecture, user centred design, modularization, lifetime extension

1. Introduction

One of the key objectives of a circular economy (CE) is to extend the lifetime of products (Potting et al., 2017). Research on CE in the field of automotive development gained a growing interest in recent years. In this field research mostly considers recycling in the CE related publications (Prochatzki et al., 2023). However, recycling is considered to be a lower rated strategy due to loss in material quality when, e.g. alloys, cannot be separated (Potting et al., 2017).

Passenger vehicles consist of multiple distinct components, a characteristic currently leveraged to manage complexity and enhance efficiency in production and supply chains. Over time, customer satisfaction with a vehicle declines, influenced by individual components (Peters et al., 2023). This decline, in turn, increases the attractiveness of new products. To prevent specific components from becoming weak links that render the entire vehicle obsolete (Ellen MacArthur Foundation, 2013), it can be argued that different strategies should be developed for different components. While some strategies for extending the lifespan of specific vehicle components already exist (Prochatzki et al., 2023), a holistic and systematic approach to integrating appropriate lifetime extending R-Strategies into vehicle design remains absent.

In the 1970s extending the lifetime of passenger vehicles was mainly related to contain deficiencies and preventing the buildup of rust at chassis and structural components. The German Federal Ministry for Research and Technology (BMFT) funded the Forschungsprojekt Langzeitauto (research project long-term car) which was one of the research projects at the time. The project was aiming for a vehicle lifetime of 20 years or 300.000 km and lower energy and material consumption during production (Braess et al., 1976).

Compared to vehicles with internal combustion engines (ICE) the share of emissions allocated to the production phase will become more relevant for battery electric vehicles when the CO2 equivalents (CO2e) produced over the full lifecycle of the vehicles are considered (VDI, 2023). Here, no fossil fuels are needed for operation. Therefore, the share of emissions from the use phase decreases depending on the share of fossil energy in the power grid.

Lifetime extension for vehicles could be a possible solution to further reduce the CO2e produced during the lifecycle of a passenger vehicle. This would require both durability and adaptability to meet not only today's customer requirements but also future customer requirements (Peters & Schleich, 2024).

The modularity of a vehicle's product architecture is seen as a possible enabler for this approach (Peters & Schleich, 2024). One example for adaptability in vehicles is the concept vehicle Eterna developed at Eindhoven University of Technology. It employs an exchangeable outer structure and a durable bottom structure. The developers place long lasting components in the bottom structure and the parts frequently exchanged by customers in the outer shell. By choosing this approach they are aiming for a lifetime of over 20 years (TU/ecomotive, 2023). A modular vehicle architecture designed for longevity by integrating lifetime extending R-Strategies for a CE and upgradability and has not been developed yet (Peters & Schleich, 2024).

In the following, the fundamentals and resulting objectives for product lifetime extension are first explained and requirements for a classification of components are derived. Based on this a classification framework is proposed. The paper closes with a discussion and an outlook on future research.

2. Theoretical background

2.1. Circular economy (CE)

A CE is an industrial system that is restorative or regenerative by intention and design, aiming for elimination of waste through design of materials, products, or systems (Ellen MacArthur Foundation, 2013). In the context of resource management, the strategies to close, narrow and slow the flow of resources have been identified. Their objective is reducing the demand for new resources in production (Bocken et al., 2016).

In order to achieve circular products, a variety of strategies to optimize a products circularity have been developed. These strategies are called R-strategies. There are numerous ways to categorize the strategies (Kirchherr et al., 2017). The structure proposed by Potting et al. (2017) is one of the most frequently cited among researchers. The proposed 9R-framework lists the R-strategies according to their respective contribution to increased circularity. It uses three categories to classify the strategies: "Smarter product use and manufacture", "Extend lifespan of product and its parts" and "Useful application of materials" ranked in descending order of their contribution to circularity (Potting et al., 2017). The framework is regarded as providing one of the more detailed categorizations of the R-strategies (Kirchherr et al., 2017).

Prochatzki et al. (2023) conduct a literature review on CE in the automotive sector. They note a growing interest in research on the concept of circularity in vehicle design. Recycling is one of the most frequently examined strategies in the literature on the automotive sector. However, it is regarded as a less effective strategy than those aiming to extend the lifetime of products (Potting et al., 2017). The authors of the review note that some components are more frequently investigated than others. They highlight the underrepresentation of other strategies, e.g. for lifetime extension (Prochatzki et al., 2023).

2.2. Product lifecycle and lifetime

An item is defined as a part, component, device, subsystem, functional unit, equipment, or system that can be individually described and considered (EN 13306:2010). Moving forward we will use the term component when referring to individual technical solutions that fulfil functions of a vehicle.

The term product lifecycle is defined as a series of stages through which an item goes from its conception to its final disposal (EN 13306:2010). The stages of a product lifecycle can be defined as the product development process, distribution, use phase, decommissioning and recycling (Bender & Gericke, 2016). The product development process comprises the stages planning, development of a solution in principle, concept development, concept design, component design, and documentation. It impacts all the following phases of the product lifecycle (Feldhusen & Grote, 2013).

In expanding upon Woodward (1997), Ashby et al. (2016) define possible lifetimes of a single product. These are defined as follows: the physical life, affected by wear; the functional life, affected by the demand for function fulfilment; the technical life, affected by improvements to the function of the original design in newer generations; the economic life, impacted by the advantage in operating cost for newer designs; the legal life, impacted by standards and legislation; and the desirability life, impacted by the perception of aesthetic design and potential changes over time. The shortest of these lifetimes is the actual expected lifetime before the first use phase comes to an end. This can result in the physical lifetime of a product being longer than the actual use phase, due to the influence of the aforementioned factors.

Extending the lifetime of a product can be advantageous from an ecological perspective. This is due to the reduction in demand for raw materials and production-related emissions associated with replacement products (Bocken et al., 2016). However, this is not always the case when considering the complete product lifecycle. An increased efficiency of a product during its use phase has the potential to offset the CO2e emissions of the production of a replacement product over time. A well-documented example of this is the case of refrigerators and washing machines (van Loon et al., 2021). Some researchers put forth the argument that designing a product for a so-called optimal lifetime may prove more beneficial than making a product more durable. Due to the dependencies between the components of a passenger vehicle finding an optimal lifetime for all of them could prove to be too complex for a single method. However, individual components could be developed according to their optimal lifetime (Carlsson et al., 2021).

Different lifetimes of individual components are also found in the context of production systems. These systems are typically constituted by a hierarchy of subsystems and components. The lifecycles of the subsystems are likely to be shorter than that of the complete system. Hanski et al. (2012) propose a framework for classifying these lifecycles. According to this framework, it is essential to have information on the lifecycles of the subsystems, to understand the lifecycle of a system.

The decision to replace a privately owned item is largely dependent on the consumer. Therefore, the replacement behaviour differs from the industrial context. Van Nes and Cramer (2005) introduce a model to gain insight into replacement decisions made by customers. This model posits that the demand for replacement arises from a relative advantage of the desired state over the actual state of the product currently owned. This relative advantage results in a lower customer satisfaction. They propose that the relative advantage is not defined by a single reason for replacement, but rather by an accumulation of factors. Moreover, the authors posit that the presence of a single identified factor is usually insufficient to achieve a critical relative advantage that would result in a replacement decision.

Haug (2016) states that the lifetime of a product can be extended by improving its so-called intrinsic resilience, meaning resilience against devaluing product-changes like decay and defects, and extrinsic resilience, defined as resilience against devaluing environmental changes like fashion trends and new technologies. These devaluing changes are expected to result in a decrease in quality until an unsatisfactory quality level is reached.

Quality is strongly connected to customer satisfaction. It is defined as “the degree to which a set of inherent characteristics of an object fulfils requirements” (ISO 9000:2015). When a component of the product is no longer able to fulfil its original purpose the quality of the product is perceived to decline. This can happen for any of the reasons outlined by Ashby (2016). Such changes may be attributed to alterations in the inherent characteristics of the product, for instance, as a result of wear, or shifts in customer requirements.

Kano et al. (1984) posit that attributes have varying impacts on customer satisfaction. They distinguish between five types of quality: must-be quality, one-dimensional quality, attractive quality, reverse quality, and indifferent quality. The must-be quality is achieved when fundamental and implicitly anticipated functions are fulfilled. There is a detrimental effect on customer satisfaction when not fulfilled but does not positively affect it. One-dimensional quality encompasses explicitly stated customer demands. The implementation of the functions contributes to satisfaction in a positive manner, whereas their absence has a negative effect. Attractive quality can be understood as an implicit requirement, representing the inverse of must-be quality. It is not necessary for the customer to be aware of the functions that they require. Therefore, the absence of these functions does not negatively impact satisfaction. The implementation of these functions is increasing the customer satisfaction. The presence of indifferent quality has no impact on satisfaction at any stage of the customer interaction with the product. Reverse quality is connected to the products providing functions that are not desired (Kano et al. 1984). The satisfaction with a product and the type of quality of an attribute can change over time (Löfgren et al., 2011).

For the German market, it can be observed that the average age of passenger vehicles has increased from 3,7 years in 1960 to 10,3 years in 2024 (Kraftfahrt-Bundesamt, 2024a). Concurrently, the overall number of passenger vehicles is increasing. The fastest growing group consists of vehicles older than 15 years. These account for 24,6% of all German passenger vehicles in 2024 compared to 19,9% in 2020 (Kraftfahrt-Bundesamt, 2020, Kraftfahrt-Bundesamt, 2024a). In the 1960s and 1970s, corrosion was the primary factor contributing to the shortened lifetime of vehicles. This led to initiatives such as the Forschungsprojekt Langzeitauto, researching corrosion-resistant designs and the utilization of diverse materials (Braess et al., 1976). In recent years, customer surveys have indicated a growing tendency among consumers to postpone the decision to purchase a new vehicle. The authors of the customer surveys attribute this to increasing prices for passenger vehicles (Deutsche Automobil Treuhand, 2024).

2.3. Modularity

The existing literature identifies five common attributes of modular products: commonality, combinability, function binding, interface standardization and loose coupling. Commonality refers to the use of a single module in multiple locations within a product. Combinability concerns the configuration of a product through a combination of modules. Function binding involves implementing a function within a single module. Interface standardization refers to providing common interfaces to connect modules. Loose coupling means having stronger connections between components within one module than the connection to components outside the module (Salvador, 2007). Modularization is the target-oriented development of these attributes of the product architecture. This entails the definition of modules and their interfaces. It is not aimed at achieving the highest possible degree of modularity. Rather, it aims at securing the greatest benefit in a specific scenario. The benefits can be achieved for the different stages of the product lifecycle, depending on the modularization method (Krause & Gebhardt, 2018).

The general procedure to developing a products modularity can be separated into four steps. At first the existing product architecture is decomposed into components suitable for the desired application. Then components are analyzed and evaluated according to module drivers. Afterwards modules are formed out of the individual components. Lastly a new product structure is derived (Krause & Gebhardt, 2018).

The modularization methods can be categorized according to the aspects they focus on. These aspects can be technical-functional, organizational-procedural, or product-strategic. Modularization according to technical-functional aspects entails the development of modules with the objective of enhancing the functionality of a product (Krause & Gebhardt, 2018). This is exemplified by the Integration Analysis Methodology, which assesses the coupling between components at different levels (Pimmler & Eppinger, 1994). Potential couplings encompass spatial configuration, energy transfer, information exchange, and material interactions, as enumerated in a Design Structure Matrix (Steward, 1981). Albers et al. (2015) present the model of product generation development. In this they state that a new version of a product is developed using variations of existing components and technical solutions. The development effort varies depending on the novelty of the desired solution and the currently available design. They indicate that certain components of a product show little changes compared to the previous design whereas others are a new design. Modularization according to organizational and procedural aspects entails optimizing the product architecture for different lifecycle phases (Krause & Gebhardt, 2018). This has the potential to facilitate the parallelization of development phases (VDI 2221:2019). Lastly, product-strategic and integrative modularization methods are designed to support a company's long-term strategic planning (Krause & Gebhardt, 2018). An example of this category is the Modular Function Deployment, which posits module drivers as the primary rationale for the development of discrete modules (Erixon, 1998).

Modularity is often seen as a potential enabler for the creation of more sustainable products. The potential benefits are expected to be felt throughout the lifecycle of a product since it is defined within the product development process. The benefits include a reduction in waste and CO2e emissions during production, the facilitation of durability, maintenance, and recycling, as well as enabling different use cases through flexibility (Machado & Morioka, 2021).

A literature review reveals that the documented benefits of modularity are predominantly evident during the production phase and that further integration of the consumer into the development process is required. The advantages of modularity have yet to be quantified for all lifecycle phases in academic research (Sonego et al., 2018). This also applies to research on modularity in the context of CE. In the

context of the automotive industry, Peters and Schleich (2024) highlight the limitations of current modularization methods in achieving circularity in product design. They assume that future modularization methods must extend beyond mere considerations of product variety and repairability to also encompass adaptability and modernization.
Schuh et al. (2023) emphasize that in a CE, the value of a product is increased during its use phase by implementing new functions and technologies in the existing product during the use phase. To achieve this, the authors identify the necessity for the development of a novel modular product architecture. The introduction of R-strategies into product design, coupled with longer product lifecycles and an increase in the number of dependencies, leads to a heightened level of complexity.

3. Methodical approach and derivation of requirements

The preceding chapter establishes the relevance of product lifetime extensions in CE and the reason for the end of a products lifetime. Customer satisfaction plays a crucial role in lifetime extension, especially for privately owned products. Literature suggests that different functions impact satisfaction to varying degrees (Kano et al., 1984) and that the effort required to develop new iterations of technical solutions for these functions also varies due to different degrees of novelty (Albers et al., 2015). The need for a methodology to develop modular product architectures that support R-strategies for lifetime extension is highlighted (Peters & Schleich, 2024). It remains unanswered what basis for the development and optimization of the modularity attributes can be used for this objective.
To support the development of a modular architecture that facilitates vehicle lifetime extension, components need to be analyzed after the decomposition according to the relevance for customer satisfaction and the potential lifetime. Therefore, the following research question is proposed: How can the components of a passenger vehicle be classified to reflect their respective impact on customer satisfaction and the replacement decision?
Taking the aforementioned considerations and the overarching objective into account, requirements (req.) for the classification of components are derived. The type of quality implemented in a component impacts the customer satisfaction is to varying degrees (Kano et al., 1984). The customer satisfaction with the product has effects on its lifetime (Van Nes & Cramer, 2005). Therefore, the developed requirements suit the different degrees of importance for customer satisfaction.
It can be assumed that there is a set of components that will remain largely unchanged when a new version of the vehicle is developed (Albers et al., 2015). This is the case when the design and performance of the components will not change significantly. The performance of newly designed components shall not provide significantly improved functions. If no redesign is required to satisfy the customer needs, the distinction between a new and a used component is insignificant to customer satisfaction. Additionally, regular use of the vehicle shall not result in wear of these components. In addition, if there is no degradation in performance due to wear, customer satisfaction will not be affected over time (Peters et al., 2023). Therefore, these components can be considered to meet the must-be quality, because their presence does not improve customer satisfaction, however, their absence would be detrimental (Kano et al., 1984). The continued use of a used component has the added benefit of avoiding the use of energy and resources to produce a new component. Requirement 1 is therefore defined to be:

Req. 1: A class shall be established for vehicle components providing basic functions that are not affected by increasing requirements and that are not subject to wear and therefore can be designed to last for the desired maximum life of the vehicle.

The issue of safety has significant implications for legislation, consumers, and manufacturers. In Germany, for instance, vehicles are required to undergo a primary inspection every two years after the first three years of their lifetime. This inspection encompasses a comprehensive assessment of the components that are crucial for ensuring safety, evaluating their condition, functionality, and implementation (StVZO, 2012, §29, Abs. 3). Considering the rising number of deficiencies in components subjected to wear over time (Kraftfahrt Bundesamt, 2024b), coupled with the prevalent inclination to sell the vehicle when such deficiencies are anticipated or already evident, it is imperative to facilitate effective maintenance. It is also important that affordable repairs are made available for components that are frequently affected by minor damage. Maintenance and repair have been identified as strategies to delay the loss in quality (Haug, 2016). These components can also be considered to meet the must-be quality, since their absence would affect customer satisfaction negatively without improving it when fully established (Kano et al., 1984). In summary the second requirement is:

Req. 2: A class shall be established for vehicle components that are affected by wear due to regular use, requiring maintainability and repairability.

The effect of technological progress on the one-dimensional quality of a product must be considered since improved performance of a new product is contributing to the relative advantage (Van Nes & Cramer, 2005). It is possible that a component has a shorter technological life than a physical life (Ashby et al., 2016). This means that the component is still capable to fulfil the function it was designed for. However, the same function provided by newer components is seen as beneficial because of e.g. higher performance. They meet one-dimensional quality requirements because customer satisfaction increases depending on the degree of function fulfilment (Kano et al., 1984). To overcome this, it is necessary to consider the integration of higher performance components that fulfil the same function when the need arises. Upgrades resulting in improved functionality can contribute to an increase in overall quality (Haug, 2016; Schuh et al., 2023). The third requirement therefore states:

Req. 3: A class shall be established for vehicle components that are affected by technological progress, requiring upgradability.

It is not always the case that new functions can be achieved with the use of existing components, even if they are upgraded. In some instances, the integration of new components might be required. Notable instances of this can be observed in the utilization of standalone devices for navigation or hands-free communication in vehicles that lack the required components. Such solutions exhibit a deficiency in the degree of integration within the vehicles. This in turn often results in the presence of visible cables that are not desired. Since these components and attributed functions were not present at the start of the use phase the customer might be unaware of the provided benefits. These are not required by the customer, therefore their absence does not harm customer satisfaction. However, their presence has a positive impact on customer satisfaction. Therefore, it meets attractive quality (Kano et al., 1984). The final requirement is:

Req. 4: A class shall be established for vehicle components that are not available at the start of production, requiring the integration of necessary components at a later stage of the use phase.

4. Classification of components

In order to address these requirements, classes of components are defined based on the degree of dependency between customer satisfaction and the expected lifetime:

- **Durable components** are not affected by wear and remain capable of fulfilling the basic functionality that is implicitly expected by the customer when a vehicle is purchased. It is unlikely that a redesign of the components based on technological progress will provide meaningful benefits to the consumer in comparison to the design used during the first production. The impact on customer satisfaction is therefore limited. The durability of the components is such that they will remain functional throughout the lifetime of the vehicle. This class of components addresses requirement 1. Possible examples could be the structural parts of the car body.
- In contrast to durable components, **wear components** are susceptible to wear due to regular use and minor damages during the use phase. The environment in which the vehicle is operated and the driver's conduct both exert an influence on the condition of the parts. It is essential that these components are easily accessible on a regular basis in terms of mileage or time. The anticipated lifetime of these components can be extrapolated from historical data. These components fulfil practical functions and require maintenance to ensure reliable performance. Requirement 2 is therefore addressed by the definition of this class. Due to the time-dependency of the quality, they are of higher relevance to the value of the passenger vehicle from the consumer perspective than durable components. However, the provided functions are also implicitly expected by the customer. Therefore, their positive contribution to satisfaction is limited. Possible wear components can be the brake pads or the bumpers.

- The **value driving components** are linked to the technological advancements in their respective fields. Over time, previous generations can no longer meet the evolving and increasing customer requirements. These customer requirements are met by newer variants of the respective components. Therefore, they need to be replaced with higher performance components. The upgrade can happen when the relative advantage becomes critical, possibly resulting in a replacement decision. However, this does not necessarily happen regularly. The components were present at the start of production of the vehicle, with the required mounting positions already in place. Such components have a positive impact on customer satisfaction when they fulfil the explicit customer requirements. Req. 3 is addressed by this class of components. An example of this could be displays and compute units required for entertainment functions.
- Req. 4 is addressed by the **attraction components** that are related to functions that are currently not available for configuration but will be present in the future. It is of importance to consider the components that will be required to fulfil future functions, as this has a significant impact on the overall quality of the vehicle. It is not possible to make a comparison between the degree of function fulfilment and that of competitive products. A possible example are sensors required for the automated and assisted driving functions identified by Peters et al. (2023). So far, a definitive sensor setup has not been established to be suitable for all driving scenarios.

Figure 1 qualitatively illustrates the expected lifetime of the proposed classes of components. The positioning of components at the upper end of the scale is associated with a higher level of customer satisfaction. The width of each block represents the anticipated lifetime of the components, without any modifications to the components. As previously indicated, the lifetime of the durable components will span the entire operational lifetime of the vehicle because of a lack of reasons to replace them over time. In contrast, the wear components will require replacement on a regular basis. The frequency is dependent on environmental aspects and the driving behaviour. Value driving components, addressing a growing relative advantage between the desired state and the current state of the vehicle, are required to be upgraded when the gap between the two states grows too large. A regular change of these components is not expected. Lastly, attraction components, which must be integrated when they become available on the market and are desired by the customer, will start their lifecycle at a later stage.

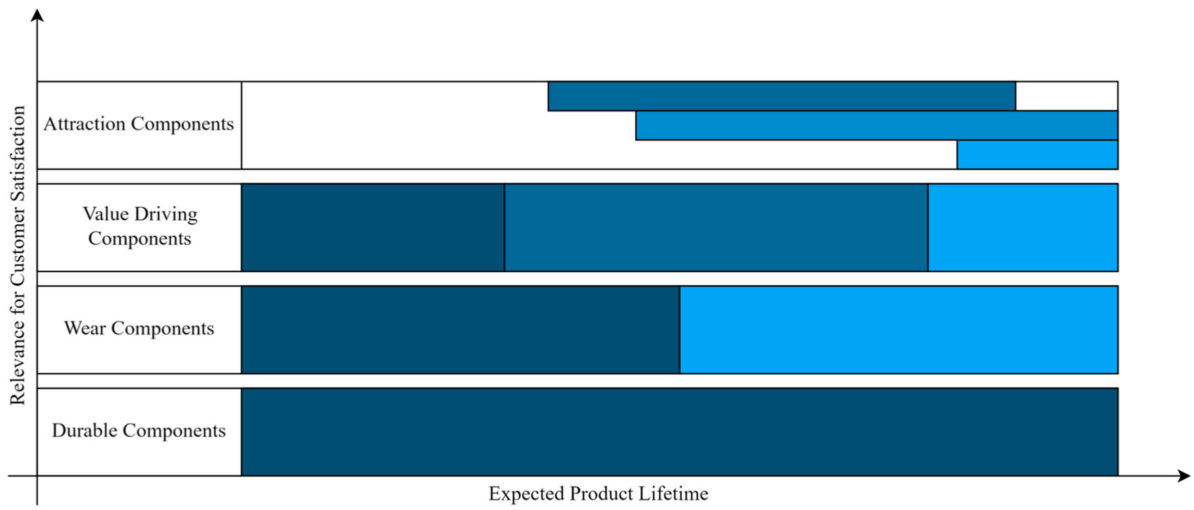

Figure 1. Lifetime model of different classes of components (own work)

5. Discussion

In the previous chapter a classification of components of a passenger vehicle was developed. The classes were developed according to the stated requirements for a classification. The differentiation between the components was made according to their relevance on customer satisfaction. They are structured in the lifetime model in ascending order to represent the relevance for customer satisfaction. Each class of components is defined to show a different behaviour regarding their expected lifetime.

The proposed lifetime model aims to providing guidance for the modularization process for vehicle lifetime extension. Depending on the classification of a component suitable strategies for lifetime extension can be chosen to improve the design of the component and its integration within the vehicle. Considering the classification of components a new modular architecture can be derived to facilitate the corresponding processes such as maintenance, repair and upgrades. Considering customer satisfaction in context of the goal of lifetime extension is an expansion of module drivers found in product-strategic and integrative modularization methods like the Modular Function Deployment (Erixon, 1998).

Repairability is a part of the vehicle design process already impacting the mounting of components. However, new requirements must be established for components that are currently assumed to have a lifetime equal to that of the vehicle as it is used today. Because of the increased longevity of a targeted vehicle structure for longevity, either the wear associated with their use or the technical advancements that render them obsolete over time may result in the need for replacement components in order to maintain the customer satisfaction of the passenger vehicle which might also lead to an adaptation of business models of OEM and third parties.

It is possible that certain components may be subject to wear yet remain relevant in terms of customer satisfaction. Therefore, they can be considered to be wear components and value driving components simultaneously. One potential illustration of this is the seating. New materials and comfort functions enabled the incorporation of ventilation and heating into seating, thereby enhancing its overall appeal. The condition of the seat is also evaluated by the customer in terms of soiling or wear through abrasion. The classification of components is therefore not exclusive. In expanding on the Offenbach approach from the field of industrial design, Brezing and Löwer (2008) put forth the integrated product model. The model posits that products invariably serve both practical and semantic functions. A product can be classified on a spectrum between the "ideal product," designed to solely fulfil a practical function, and an "artwork", designed solely to fulfil a semantic function. The position on the spectrum is based on the impact of the desired functions during the design process. Additionally, customer requirements develop over time. Attractive quality attributes over time can become one-dimensional quality attributes (Löfgren et al., 2011). Therefore, in the presented model components can be considered part of multiple classes depending on the context. This has potential implications on the modularization since the classification aims to provide guidance during the development phase. Designers therefore must evaluate the relevance of the component for customer satisfaction and its lifetime behaviour to provide suitable lifetime extension strategies.

The presented model does not explicitly address the legal lifetime of a component. Some legal changes are introduced with minimal advance notice. As evidenced by the European debate surrounding the prohibition of ICE in passenger vehicles after a specified date (Visnic, 2023), legislation serves as a crucial source of requirements for new vehicle design, although the precise timeframes remain challenging to anticipate for manufacturers. Furthermore, it can be argued that while the satisfaction of customers with a vehicle is related to legislation, as evidenced by the decline in value of diesel cars during the proposed city ban for these models in Germany, the value of the vehicle is also contingent upon the technologies that legislation can impact. Therefore, in the event of a change in the legally required features, these will need to be altered or added, like attraction or value driving components.

6. Summary and future research

In a CE extending the lifetime of a product is one goal. To enable longevity, the product should satisfy the customer requirements during its entire lifetime. To extend the lifetime it is necessary that the relative advantage, identified by Van Nes and Cramer (2005), does not reach a critical limit. The type of quality fulfilled by a component impacts customer satisfaction (Kano et al., 1984). It can be argued that some components of a passenger vehicle are of higher importance to customer satisfaction than others. The objective of this paper was to define classes of components to provide a foundation for the modularization of a long-lasting vehicle. To maintain customer satisfaction, requirements were defined for a classification targeting the different types of quality according to Kano et al. (1984). In total we defined four classes of components. An exclusive classification is not pursued, given that functions typically associated with design and engineering are often fulfilled by a single component (Brezing & Löwer, 2008).

Future research should provide empirical data on the relevance of specific components for customer satisfaction aiming to evaluate the validity of the classification and to answer the question which components are part of the proposed classes. Additionally, research could use this classification model for components to develop R-strategies for the anticipated lifetime and to increase customer satisfaction with long-lasting vehicles. Based on the classification and requirements derived from suitable lifetime extension strategies a modularization method can be developed to facilitate not only the lifespan extension of individual components but entire vehicles.

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