INTERNATIONAL DESIGN CONFERENCE – DESIGN 2024
https://doi.org/10.1017/pds.2024.253

Product changes from various viewpoints along the product lifecycle – an empirical study

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Abstract

From an economic perspective, the appeal of a product diminishes over time. However, volatile markets and divergent technological advancements make it challenging to anticipate when and to what extent changes will be necessary. Therefore, it is important to be able to integrate changes after a product's launch. This paper provides an overview of different perspectives on the product lifecycle. In addition, the paper presents an empirical study on implementing changes at an automobile manufacturer.

Keywords: change management, design for x (DfX), product families, product lifecycle

1. Introduction

The success of a product on the market over its lifetime depends on different factors. From an economic point of view, the attractiveness of a product decreases over time. To avoid a decline in demand, companies take measures to modify their products. But due to volatile markets and diverging evolution of technologies, it is difficult to predict when and which scope to modify (Fricke and Schulz, 2005). For example, the automotive industry is in a period of upheaval, because of new technologies for alternative drives that emerged. Moreover, with the evolution of driver assistance systems towards autonomous driving, the interior design and entertainment of passengers gained more importance compared to the driving dynamics. These new technologies concern different components of a product and evolve at a different pace. Therefore, it is essential for companies to be able to integrate recent developments. However, product changes, especially after launch, have a negative connotation and are avoided (Fricke and Schulz, 2005; Kratzer et al., 2021).

This paper analyses the integration of change in order to derive measures regarding product design to facilitate the implementation of future unknown changes. Based on the various views on the product lifecycle the necessity of change and the impact on product development are explained. In addition, the paper presents an empirical study about the challenges concerning the implementation of changes, conducted at an automobile manufacturer.

2. Research background

This chapter provides a description of attractiveness related product changes from various viewpoints along the product lifecycle.

2.1. Different views on the product lifecycle

The product lifecycle can be regarded from different perspectives such as the product development, the user, market or sustainability. According to the varying viewpoints, different types of product lifecycles are defined. The life cycle assessment for example tracks the environmental impact of a product along its lifecycle, from sourcing of material to its recycling (ISO 14040, 2006; Ishii et al., 1994). In the following, product lifecycles which focus on the evolution of technical products and the need for continuous modification to ensure market success are outlined. Figure 1 schematically illustrates them and their interrelationships.

The **technological product lifecycle** describes the technological evolution of a product via the different versions of its type (Pahl et al., 2007). Depending on the scope of change, the product is relaunched either as a new version of the same generation or a new generation. In Figure 1, the product is launched as version 1.0 of the product generation 1. After three relaunches with minor modifications (version 1.1, 1.2, 1.3), a new generation is developed and launched as version 2.0. This evolution can be seen at the BMW 5 series limousine. The G30 was launched as the first version (V 1.0) of the so-called cluster architecture in 2017. After three years the G30 was replaced by a so-called "facelift" (version V 1.1 with minor modifications), which is typical for the German automobile manufacturer. The successor of the G30, called G60, was launched 2023 within the same generation (version V1.2). According to this logic, its facelift will be launched in a few years (version V 1.3) with minor modifications concerning the design and technology. Its successor is announced to contain major changes and will constitute a new product generation the so-called "Neue Klasse".

The **intrinsic product lifecycle** provides a closer look at the life phases of each product version. According to Pahl et al. (2007), this is the most common view of the product lifecycle. It starts with the idea of the product, its development and production, followed by its sale, the handover to the customer and finally its recycling (Pahl et al., 2007). Eigner and Stelzer (2009) further subdivide the life phase development into product planning, development, and process planning. Sales and usage are summarised as one phase. The lifetime of the intrinsic product lifecycle depends on the specific product. The end of life can be reached due to different physical causes such as malfunctions or breakdowns (Umeda et al., 2007). However, products are also disposed because of a loss in attractiveness (Umeda et al., 2007). Therefore, Umeda et al. (2007) define the expression "value lifetime" which is the time span until the user is unsatisfied with the product's design and features despite full functionality. Their study reveals that the disposal patterns concerning value disposal vary, even for the same type of product. The different perception of product value needs to be considered in the lifecycle strategy of companies (Umeda et al., 2007), which in turn is represented in the technological product lifecycle.

The development of the attractivity of a product over time is depicted in the **economic product lifecycle.** It shows the typical development of the revenue of a product over its market presence (see Figure 1) (Pahl et al., 2007). The revenue reflects the number of sold products and the prize that customers are willing to pay, hence a product's attractiveness. From the start of production on, the production slowly ramps-up the producible quantity of the product. After the ramp-up phase, the demand rises and thus the revenue. After a while the demand declines, and the saturation is reached. There are various reasons for this: The delayed launch of a similar product attracts more customers. Or technological progress raises the desire for a new product and hence reduces the attractiveness of the product. At this point action must be taken to either modify the product or replace it with a successor (Fricke and Schulz, 2005; Pahl et al., 2007; Petrick and Echols, 2004).

The technological progress of products depends on the different technologies incorporated in the product. As indicated in Figure 1 (see top right) each technology (a, b and c) undergoes its own **technology lifecycle**. The performance or maturity of technologies evolve over time, typically following an S-curve (Pahl et al., 2007; Petrick and Echols, 2004). The evolution of the system starts slowly and gains momentum as more resources are invested in development (Petrick and Echols, 2004). It continues until it reaches its physically defined maximum performance (Pahl et al., 2007). Meanwhile, an alternative technology may emerge for the same purpose and outperform the established one, but usually not until the established one has reached its inflection point (Petrick and Echols, 2004).

The diagram in the top right corner illustrates how the cycles of different technologies relate to the technological product lifecycle. It is assumed that the product contains technologies a, b, and c, which evolve independently. The product is launched with technologies (a, b and c) having a certain degree of maturity that reflects the state of the art (Pahl et al., 2007). At the start of version 1.0's lifecycle, technologies b and c are close to their inflection point. Considering version 1.1, the performance of

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technology a improved significantly and almost reaches its maximum. Then, new technologies replace technologies b and c, which is known as a technology leap. Although, there were technological leaps ready to integrate in versions 1.1 and 1.3 (facelifts), they were postponed to versions 1.2 respectively 2.0 (as indicated by the arrows), due to the fact that only minor changes were planned for the facelifts. Even, if there were no technological leaps, the product attractiveness would decline over time (Gerth, 2015). Product features that arouse enthusiasm at the time of launch, turn into basic features that customers take for granted later (Gerth, 2015). However, a product comprises various technologies to fulfil its functions, and each technology is underlying its own technology lifecycle. As a result, the product requires continuous modification to remain competitive.

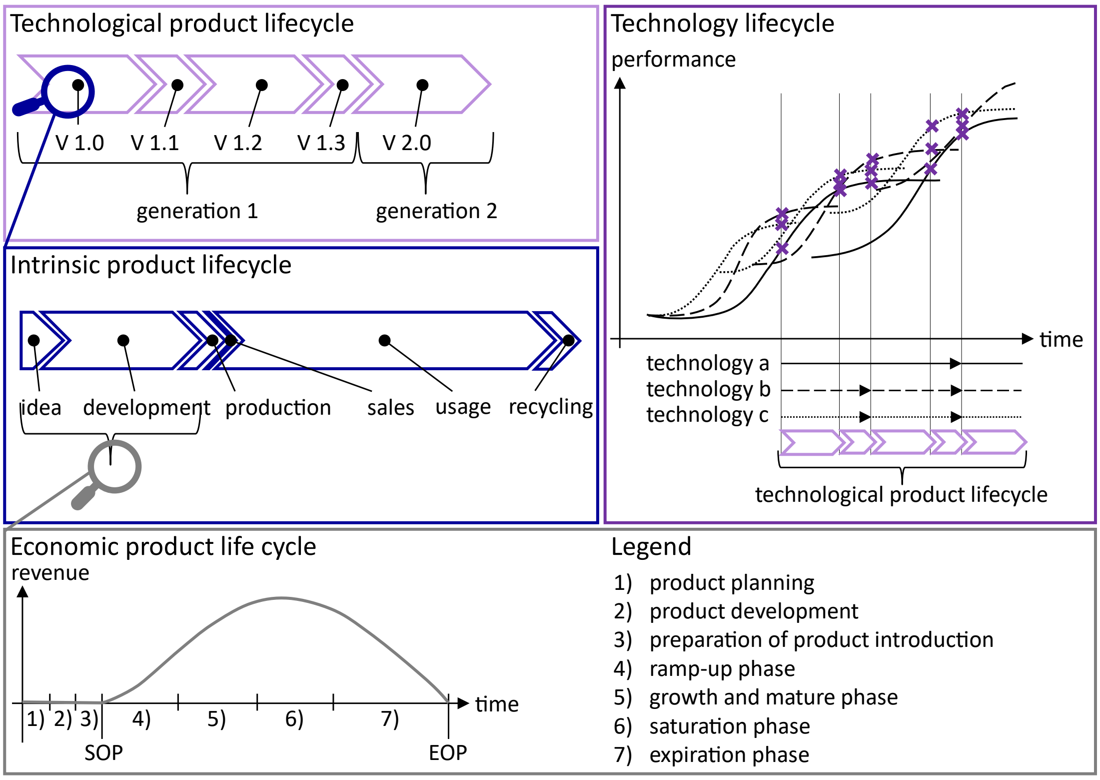

Figure 1. Different views on the product lifecycle (partially based on Pahl et al. (2007))

2.2. Change and Release Management

Change Management is the process of handling changes, from the initial change request to the implementation and continuous optimisation of the change process. The main tasks are the evaluation of change requests and the scheduling and controlling of the whole change process. (Lindemann, 2016)
In addition, the **Release Management** focusses on the synchronisation of change integration to reduce the testing effort. Therefore, occurring changes are evaluated and clustered in terms of their necessity and due date. For each cluster a release cycle is defined. The modular release management by Schuh et al. (2016) additionally considers the change effort and customer relevance. Clusters, that are easy to change and strongly contribute to product attractiveness, are assigned to higher release frequency. In contrast, major releases contain clusters, that provide the product's basic functions and cause high change effort such as facelifts (Schuh et al., 2016).
It is well known by the Rule of Ten, that costs for changes increase exponentially over time. Consequently, frontloading of changes and the reduction of changes to a minimum are the preferred strategies. (Fricke and Schulz, 2005; Lindemann, 2016) However changes are unavoidable and occur throughout the whole (intrinsic) product lifecycle (Fricke and Schulz, 2005; Kratzer et al., 2021; Schuh et al., 2016). Approaches for change-friendly product design, to keep the effort for future changes low, are scarce (Lindemann, Schuh 2015). There are many approaches which use forecasts or retrospectives (based on data from the Change Management) to predict the likelihood of changes and to estimate the

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change effort (Beibl et al., 2023). Further research uses matrices for the analysis of change concerning their cause and potential effects (de Weck, 2007; Greve et al., 2021; Raudberget et al., 2017; Schuh et al., 2017). Other approaches (Bischof and Blessing, 2007; Fricke and Schulz, 2005; Palani Rajan et al., 2005; Tilstra et al., 2015) outline principles for the design for changeability. They are derived from previous research and via product analysis. Albers et al. (2022) introduce an approach for co-design of the product portfolio and the production system to facilitate the implementation of foreseen product changes in the production system as well, along the lifecycle. Nevertheless, these approaches solely provide methodical support for the consideration of anticipated or planned changes in design. However, volatile markets and fast technology cycles are challenging companies, especially those in the automotive industry with long time-to-market and product lifecycles.

3. Identification of challenges concerning the implementation of changes

The literature provides approaches to evaluate the change effort. Procedural support is provided by the Change and Release Management. However, there is a shortage of methodical support on how to design products to facilitate the implementation of future unforeseeable changes (Beibl et al., 2023; Lindemann, 2016). The provided guidelines are either too generic or too product specific to be generally applicable. The guidelines are often derived from product analysis and refer to specific design elements of the application example.

Therefore, a study was carried out on the challenges faced by an automobile manufacturer during the implementation of changes to identify design aspects that facilitate or impede the implementation of changes.

3.1. Design and conduct of the survey

The survey was conducted at an automobile manufacturer with experts from different departments and levels of hierarchy. Each of them has more than five years of professional experience and most of them more than eleven years. The departments range from research and product development to purchase and production. They all have to deal with implementing product changes, but in different ways.

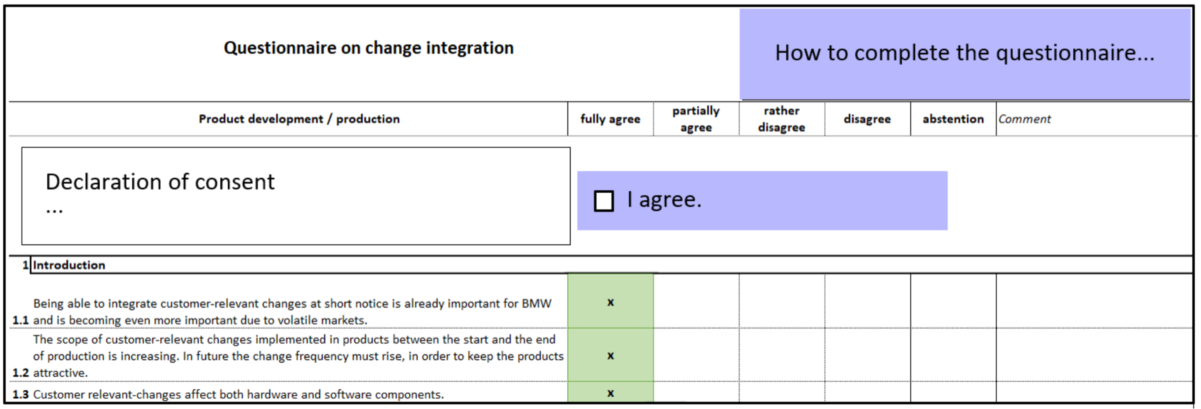
We divided the survey into two parts. The **first part** was an explorative survey which aimed at gaining a broad view (Bogner et al., 2014; Brüsemeister, 2008) about the implementation of changes, especially its challenges, and collecting a variety of examples. For this kind of data collection, expert interviews with a semi-structured interview guide and open questions are a suitable method (Bogner et al., 2014). Own professional experience at the automobile manufacturer and preliminary discussions with relevant departments facilitated the design of the interview guide. The extent of this qualitative study was determined by a termination criterion and not a specific number of interviews. The reasonable number of interviews is reached when the interviewed experts do not mention further aspects concerning the topic (Nascimento et al., 2018).

The **second part of the survey** served as a validation of the findings from the first part of the survey. Therefore, we set up a questionnaire with theses (Brüsemeister, 2008) that describe general design characteristics which ease or impede the modification of products. The theses were derived from the protocols of the expert interviews via deductive coding analysis and clustering of statements. The questionnaire was divided into product and production related aspects. A second group of participants, distinct from the first group, was asked to confirm them. The group consisted of twenty experts, ten from product development and ten from production with a similar demographic distribution as the first group. The assessment scheme ranged from "I totally agree" to "I do not agree" and the possibility for abstention. Optional comments could be added as well in a separate field (see Figure 2).

The whole survey was conducted via online meetings.

The **first part of the survey** was designed in the form of an open dialog. The interviews were not recorded, only main points were noted down. As an introduction we presented the motivation for measures for product family modifications and emphasised the focus on product design aspects. Depending on the conversation's flow we asked for examples or more details about the challenges and change-friendly aspects. Most of the time the experts mentioned examples of change implementation and categorized them as "easy to implement", "challenging" or "time-consuming". They did not state generally applicable design rules for products and the corresponding production system, to ease the implementation of future changes. The examples showed that the change effort strongly depends on the design of the product and its corresponding production system. During the interviews, some of the experts recommended colleagues to discuss further aspects or in more detail. Through that suitable experts were identified, and a reasonable number of 22 interviews was reached.

Based on the results of the first part, the **second part of the survey** was set up. For the second part of the survey another group of experts was asked to confirm the statements derived from the first group of interviewed experts. At the beginning of each online meeting, we gave a short introduction about the topic, similar to the first part of the survey and distributed the questionnaire (see Figure 2) to the experts being interviewed. They filled in the questionnaire and returned it within a few days. Many of them added comments to confirm their answers, sometimes with a real example. In some cases, the additional comments showed that the assessment scheme was misunderstood. Neither the interview guide for the first part nor the questionnaire for the second part of the survey were adjusted during the study.


Questionnaire on change integration

How to complete the questionnaire...

Product development / production	fully agree	partially agree	rather disagree	disagree	abstention	Comment
Declaration of consent ...	☐ I agree.					
1 Introduction						
1.1 Being able to integrate customer-relevant changes at short notice is already important for BMW and is becoming even more important due to volatile markets.	x					
1.2 The scope of customer-relevant changes implemented in products between the start and the end of production is increasing. In future the change frequency must rise, in order to keep the products attractive.	x					
1.3 Customer relevant-changes affect both hardware and software components.	x					

Figure 2. Extract of the questionnaire

3.2. Challenges concerning product modification

This chapter provides a summary of the most relevant findings from the survey, conducted at an automobile manufacturer.

Initiating the interviews, the importance of product changes, especially after the launch were discussed. The interviewed experts confirmed their relevance and explained that the planned modifications for facelifts become more extensive. Products launched afterwards (by competitors or the own company) and fast development of technologies lead to a loss of attractiveness and thus force the company to enhance their products.

Volatile markets make it more difficult to predict the market requirements and thus impede long term planning. Especially product families of cars with long product lifecycles are affected by the decreasing forecast quality. A product family of cars and their modifications are planned about twenty years ahead. The time span covers the time from the first idea, via the staggered launches of cars from the product family to the phase out of the last car. The experts of the product development and the production agreed that change integration gains more and more importance due to volatile markets and technological leaps (except two abstentions).

Thesis 1 in Figure 3 states that dividing changes into smaller scopes of change, released in shorter time intervals, offers higher transparency about the change effort and the possibility for corrective action. This was not confirmed by three experts (including one abstention). The optional comments contain the explanation that the costs caused by change integration are not proportional to the scope of change and that the bureaucratic effort increases. On the other hand, only six out of ten experts confirmed thesis 2 which suggests, that as maturity increases, tests should be conducted at module level rather than at component level to reduce testing efforts. One of the experts explained that components with low maturity and unknown interaction with other components need to be tested separately prior to tests at module or total vehicle level.

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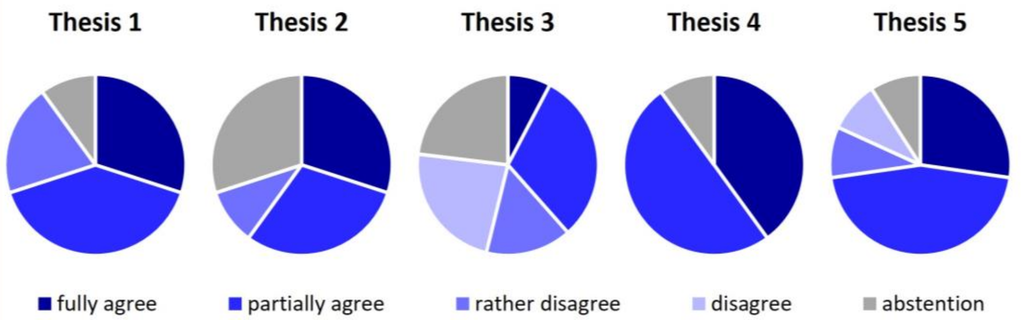
In the interviews, several experts mentioned the importance of transparency: Knowing which components are affected by change and their commonal usage in other products. A distinction must be made here between the integration of changes into a new product to be manufactured and products that are already in customer ownership. With regard to the latter, no hardware-related changes are taken into account in case of automobile manufacturers, while software changes are easy to implement over the air. However, it was mentioned that software changes often require specific code variants to run on the system environment from previous product versions, resulting in an increase in variety. Experts explained further that software-related changes are limited by hardware. Reasons are insufficient computing power and /or storage capacity and non-existent ports and cables for data flows. Software-related changes are not in general easy to integrate (see thesis 3). They require testing as well and can lead to changes of the hardware. In addition, the technology cycles of software are shorter than that of hardware components.
A product can change regarding functionality, performance, and design. The one-to-one mapping of a function to a component makes future changes easier and reduces the propagation of changes in the product (see thesis 4). However, the experts mentioned that this is hard to reach in a complex product like a car where for example the driving function is realized by an interplay of several control units and sensors.



Thesis 1: Dividing changes into smaller scopes, released at shorter time intervals, offers higher transparency about the change effort and the possibility for corrective action.

Thesis 2: As maturity increases, tests should be performed at module level rather than individual component tests in order to reduce testing effort.

Thesis 3: Software-related changes are easy to integrate as long as they do not cause any hardware-related changes to control devices.

Thesis 4: The one-to-one mapping of a function to a component makes future changes easier and reduces the interaction between components.

Thesis 5: Different types of buffers facilitate the integration of future changes. However, volatile markets make it difficult to decide where and what kind of buffers to build in.

Figure 3. Extract of the results

A change in functionality or performance can be realized without a change of the outer shape (geometry, interfaces). The experts observe that electronical devices for example increase in power and storage while decreasing in size. However, some of the interviewed experts recommended to include buffers concerning computing power and storage capacity to ease future changes, since the share of software-based functionality increases. In the second part of the survey, eight out of ten experts confirmed thesis 5, which suggests the integration of buffers to facilitate future changes. The optional comments reveal that in particular buffers regarding the performance of control devices and processors facilitate future modifications. Arguments against it are increasing costs. Buffers concerning the installation space are seen critical, because installation space is scarce in cars and buffers for future changes are hard to predict.
In general, components of a car are densely packed so that additional components or an increase in a component's size can lead to a relocation of components in the product and a redesign. Geometrical changes of the component can impede the installation space of other components and thus cause further adaptations. However, standardized interfaces and clearly defined requirements were mentioned to facilitate the implementation of changes and the development process overall.
Testing und approval by the authorities of different countries have a great influence on the date of implementation and are time-consuming. Because of the extensive testing procedures which require

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expensive prototypes, automobile manufacturers try to postpone changes to the next major release to reduce the testing effort. For the approval by the authorities, prototypes produced with the series production processes must be used. Moreover, changes that require endurance or winter testing are more time-consuming and bound to particular timeframes.

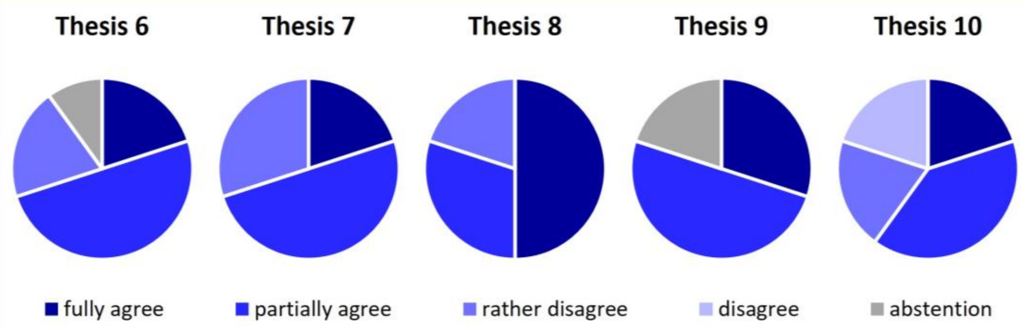
In general, prototypes are not only used by the development department for functional testing, but also to proof a product's manufacturability. At the interviewed automobile manufacturer prototypes are produced at a separate plant to avoid any disturbance of the series production. Only the pre-series cars with the final component quality are produced in the series production lines. However, there are some exceptions. The paint shop is designed to produce a higher quantity of cars in the series production lines, through the inclusion of a buffer for prototype production. The production process is based on product specific software programs and manual work which can be adapted. Sometimes single prototypes are produced in the series production lines, but only in case of minor deviations from the series processes.

The interviews with experts from the production revealed that the flow production shows some limitations concerning the implementation of changes, due to its basic structure (line structure and rigidly connected machines with a cycle time) (see Figure 4). Several experts stressed that any product changes which cause changes of the assembly sequence or an increase of the cycle time, are usually denied by the production planner. Changes of the assembly sequence either lead to a reallocation of manual tasks along the production line or to structural changes of the machine layout in the worst case. Many experts admitted that they are not familiar with other organizational forms of the production than the flow production. But they agreed that bypasses or decoupled process steps facilitate the integration of changes (compare thesis 9). However, parallelization of one and the same process step is seen critical, due to the difficult identification of the root cause of deviations in product quality.

The expert’s opinions diverge regarding thesis 10, which states that changes of the joining process can be solved through reprogramming of machines, if no equipment is involved. In comparison to automated processes, manual assembly processes are easy to adapt, according to the experts.

Furthermore, interfaces were mentioned to be crucial for the integration of new components. Not only the interfaces within the product but also the contact area for grippers or fixtures are relevant.

In general, the experts stated in the interviews, that the change effort strongly depends on the desired change and the specific component or product. Furthermore, the implementation period and date are currently not prioritised. Changes are mainly integrated at weekends and planned production downtimes.



Thesis 6: The integration of a new component version can lead to an adaption of the assembly sequence. An adaption of the assembly sequence is not possible in a flow production, because of its sequential interlinkage of machines.

Thesis 7: In a flow production, only a limited scope of additional process steps can be integrated without affecting the cycle time.

Thesis 8: If certain product variants require new machines for additional process steps, all products produced on the production line must pass the machines, even though no work is being done there.

Thesis 9: Additional process steps are easier to implement in a production system with an area structure than a line structure. An area structure can be expanded more easily (without structural change and production downtime), due to its flexible interlinkage of machines.

Thesis 10: Changes to the joining process can be integrated simply by reprogramming the machines, if components are joined by machines without any fixtures/ equipment.

Figure 4. Extract of the results

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4. Discussion

Although the focus of the survey lied on design challenges, processes and mindset of the company were frequently mentioned as important aspects regarding the implementation of change. The development process, including decision-making processes, must be designed to allow continuous product modifications at the automobile manufacturer. This requires an adaption of supply contracts in terms of order scope and duration.

Regarding product design, no quantifiable characteristics for change-friendly design were mentioned. The experts' responses were mostly in the form of examples of change integration with a categorisation as easy or difficult to implement. However, characteristics of modularity according to the definitions by Schwede et al. (2022) and Salvador (2007) were identified in the results. Modularity is often stated as an enabler for flexibility (Bonvoisin et al., 2016; Otto et al., 2016; Sanchez, 2004; Schwede et al., 2022). The following characteristics of modular products were described as facilitating the integration of change in a car.

- Adherence to standardized interfaces within the product
- Function binding to decouple the interaction between modules
- Oversizing in terms of computing performance and storage capacity

Commonality and combinability of modules were not considered to facilitate the implementation of changes but to facilitate the derivation of new variants.

Strict constraints of the production system were stated: Changes to the assembly sequence and additional process steps, which affect the cycle time, will not be accepted. However, each part of the production system provides different types of flexibility to facilitate the implementation of changes. Moreover, every change means a disruption to the series production and has a negative impact on productivity.

Besides the mentioned characteristics of modular products, the decoupled modules represent assembly groups. By strategic modularisation of a product family, the production system and its processes are indirectly modularised. Module drivers, such as parallelisation or separate testing, lead to the decoupling of modules and their assembly steps (Schwede et al., 2023). This in turn limits the impact of changes to an assembly group (Krause and Gebhardt, 2023).

The survey shows that redesign of the product alone is not sufficient to facilitate the implementation of changes. If the production system mirrors the modular product structure, synergies can be used to overcome some of the current challenges and to facilitate the implementation of future changes. Therefore, the production system needs to be redesigned as well. The presented findings can be used as a guidance for the modular redesign of the product and the production system at the interviewed automobile manufacturer.

5. Conclusion and outlook

This paper provides an overview of different perspectives on product change along the product lifecycle and emphasises the importance of being able to react to the divergent technology lifecycles of software and hardware components within a product. A survey of the challenges faced by an automobile manufacturer in implementing changes is also presented. Its goal was to identify design aspects that facilitate or impede the implementation of changes. Therefore, the survey was divided in an exploratory part with semi-structured expert interviews, followed by a questionnaire to validate the theses derived from the interviews.

The survey shows that the change effort strongly depends on the specific design of the product and the corresponding production system. The widely used flow production limits the product design regarding the assembly content and sequence. Within a company, different production areas possess varying capabilities with regard to the integration of changes. However, the product must be designed in such a way to fit into the existing production system. Adherence to interfaces and installation space are important for the integration of changes within the product. The product's approval by the authorities constitutes a major challenge regarding the testing effort and impedes high frequencies of changes.

The findings of the survey can be used as strategic aspects in the modular redesign of the product and production system of the company surveyed to overcome the current challenges. The development of methodical support to consider change-friendly design in the development process will be part of future research.

Acknowledgement

Thanks go to the Bayerische Motoren Werke AG for funding the publication fees of this article and the conference participation. Furthermore, we would like to thank all the participants of the survey.

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