ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
ID: TG-20170501101521

Original scientific paper

SUSTAINABLE PRODUCT DEVELOPMENT: PROVISION OF INFORMATION IN EARLY AUTOMOTIVE ENGINEERING PHASES

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Abstract: Sustainable product development is an important influencing factor in automotive engineering, whereby a comprehensive evaluation of its efforts and benefits is very complex. In addition, lots of information is not available in advance of mass production. This leads to the question, how results from impact assessment can be transferred to the beginning of the development process, where important decisions about product and production characteristics are made. The present paper discusses approaches for life cycle estimation and decision support in the concept phase of automotive engineering, especially focusing on the design engineer's requirements. It includes an overview of current development processes and discusses by use of examples different approaches to integrate relevant information concerning sustainable product development in development processes.

Keywords: sustainable product development; technology management; automotive industry; early product development phases

1 INTRODUCTION

Today, automotive development has to face numerous exciting challenges. The major reasons for that are a rising globalization, steadily increasing customer demands worldwide, as well as the fast advances in technological terms, e.g. alternative propulsion systems, new materials and innovations in the field of electronics and automation. During the past decades, automotive development has been characterized significantly by a growing share of intelligent components, increasing technical complexity of vehicles and vehicles modules, as well as steadily increasing model ranges. The manifold model types require the development of different body styles, different propulsion systems as well as different comfort functions and interior configurations. Simultaneously, the rising globalization yields to a stronger competition amongst the OEMs[1], and that results in the demand of accelerating the development, in order to introduce innovative products to the global market as fast as possible. On the other hand, the production period and number of produced units per car model decrease [1]. The increasing complexity of product technology and variety challenge both the entire product development and the production processes. In addition, decrease of product life cycles duration also demands shorter product development times [2]. Furthermore, a stronger focus on future environmental challenges and sustainability is required. In the last two decades, the energy consumption and hazardous emissions during the use phase of a car have been in the main focus of automotive engineering, and will be in future. But besides that, the phase of production and end of life gains in importance, which can be seen by a steadily increasing number of legislation directives and guidelines concerning the use, recovery and re-use of materials in the vehicle. To meet these development trends, the present paper discusses an integration of novel sustainable materials and technologies in state of the art vehicle development processes, especially focusing on early development stages.

In Chapter 2, the relevant development phases are explained. Chapter 3 deals with life cycle-relevant considerations in the development process. In Chapter 4, approaches for the provision of life cycle-relevant information in early development phases are discussed. Chapter 5 closes with a short summary.

2 THE AUTOMOTIVE DEVELOPMENT PROCESS

A modern vehicle consists of several thousand parts. Besides bringing the passenger from A to B, a broad range of further functions are being integrated into the car, ensuring e.g. safety, environmental standards or comfort for the passenger. To create such a complex machine and to consider previously described boundary conditions, a flexible development and production process is required, as can be seen in Fig. 1.

The automotive development process principally consists of five main process phases: the definition phase, the concept phase, the pre-development, the series development, and early stages of the production phase. Within the initial definition phase, the requirements on the concept are collected. This includes all boundary conditions targeting legislative, consumer- or company- related aspects. It also covers the consideration of possible production facilities, basic geometric dimensions and functional requirements. The subsequently performed phase that has main impact on product characteristics and further development is explained in the following section.

[1] OEM: original equipment manufacturer

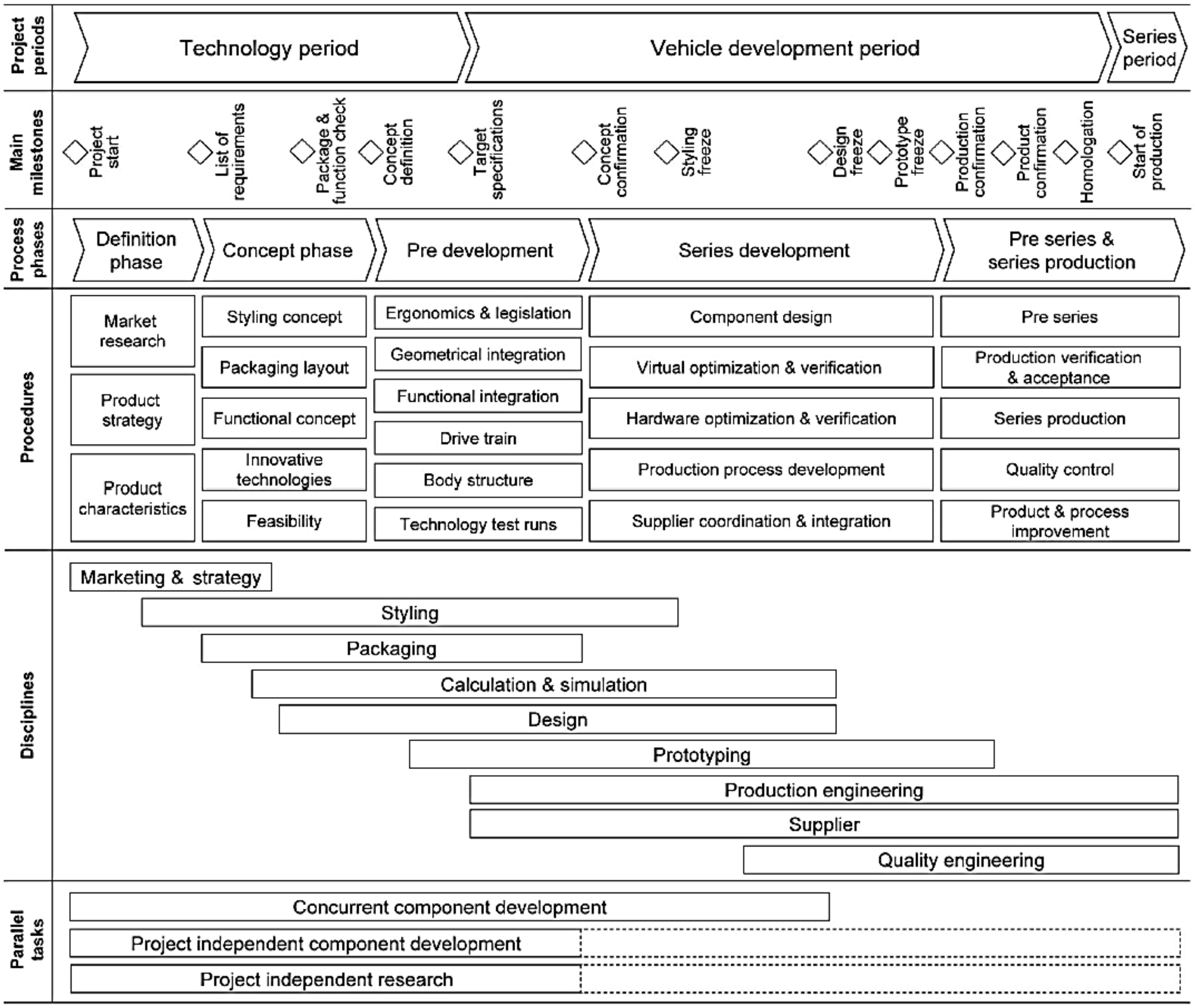

Figure 1 Principal stages in a typical state-of-the-art full-vehicle development process [3]

2.1 Concept phase

The definition phase is followed by the initial concept phase. Within this process step, first visions and ideas of the vehicle come to life; this ranges from the analysis of potential innovative technologies, first 3D drafts of spatial requirements (see Fig. 2), and an initial consideration of vehicle functions.

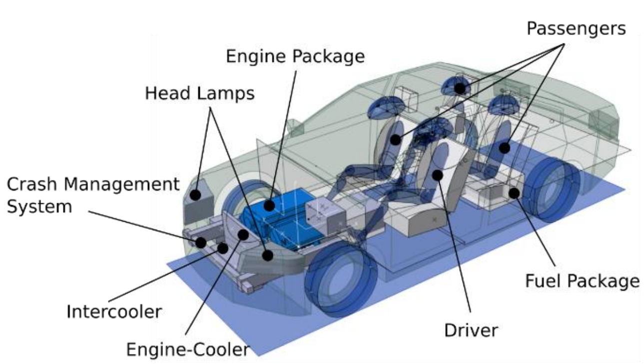

Figure 2 Preliminary 3D vehicle package as a result of the concept phase [13]

The result of the initial concept phase is a basic selection of possible suitable concept variants in the context of the defined technological and economical boundary conditions. Mostly, design principles are based on previous developments and experiences of engineers. After the initial concept phase has been passed successfully, the detail concept phase begins. In this phase, the preliminary concept ideas are refined, leading to further deeper analysis, targeting detailed 3D-CAD design models, more detailed package investigations, consideration of different styling concepts and the simulation of vehicle functions. The final step in the concept phase represents the concept decision, which is responsible for a proper selection of the detail concept. This means, if several concepts have been developed, at this point, the concept that is selected best suites to fulfill the stated requirements at the beginning of the process. As a result, dimensions of the basic vehicle architecture are defined, as shown in Fig. 3.

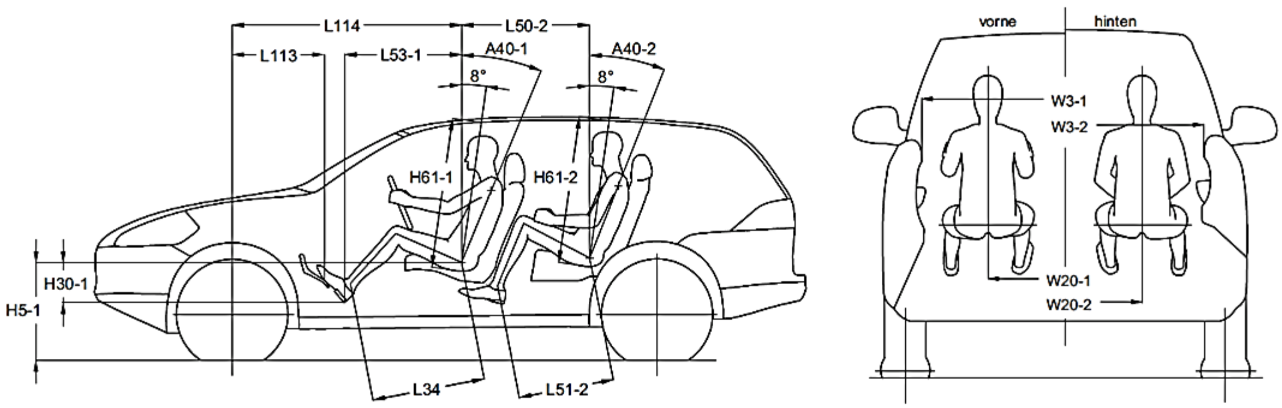

Figure 3 Defined basic vehicle dimensions in the concept phase (extract) [4]

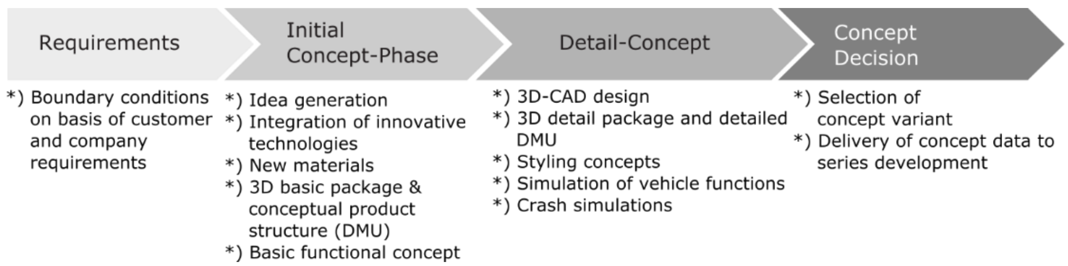

Figure 4 Steps of the early phase of development processes in automotive industry

As a conclusion, the main decisions for the development of a new vehicle or technology are made within this described four-step development process in the early stage of vehicle development (Fig. 4).

3 LIFE CYCLE CONSIDERATIONS IN THE AUTOMOTIVE DEVELOPMENT PROCESS

In this paper, the term *life cycle considerations* addresses the consideration of mainly ecologic and economic, and social impacts along the entire life cycle of a car (Fig. 5).

Figure 5 Schematic life cycle of a car

Focusing on automotive development processes, the life cycle starts with the requirements definition phase during vehicle conception. Currently, regarding life cycle considerations, sustainable automotive product development mainly focuses on existing directives to ensure compliance with material prohibitions and environmental regulations in vehicle production and end of life. One example of legal conditions is the ELV-directive of the European Union, which addresses the end-of-life treatment of vehicles [5]. Another focus of legislative lies in the reduction of greenhouse gas emissions and pollutants during operation. Therefore, the legal conditions are described in [6]. Considering the in-use phase of a car, most important fields of research in the area of energy demand and emissions reduction are

- mass reduction by lightweight construction (using high-strength alloys, light metal, fiber-reinforced plastics, multi-material construction),
- increasing the efficiency of the conventional internal combustion engines, hybridization and development of alternative drive systems, e.g. electrification of the powertrain [2].

Considering the production phase of a car, OEM's research and development strategies more and more focus on the reduction of environmental impacts, such as energy and resource demand or pollution emissions, as numerous environmental declarations from the automotive industry can be referred. One example can be seen in [7].

The next level of sustainable production is defined by the integration of sustainable materials in the car. A relatively simple example is the use of recycled materials (e.g. steel or plastics) and renewable materials (e.g. hemp, flax or wood) for parts in the vehicle interior. The simplicity of this step can be found in two reasons. On the one hand, technical requirements (e.g. stiffness) are lower in relation to structure-parts like doors or the car body. On the other hand, the integration of these parts does not necessarily intersect with defined requirements from the concept phase, as long as technical and geometric requirements are still fulfilled. As an example, the replacement of a standard hat rack by another, made of renewable materials and with the same geometry, does not need to be decided in the concept phase, but can be done in the later series development process step (Fig. 1).

The use of innovative sustainable materials in components that need to fulfil higher technical requirements may influence the defined properties from the concept phase.

2.2 Impacts of life cycle considerations on the concept phase

Early stages in product development are of particular importance for cost reduction and improvements regarding sustainability, since the influence and saving potentials are the highest in this phase of the development [8]. In the early phases of the automotive conceptual development process, many decisions are made, which define the properties of the new vehicle, module, or at least a component to be developed. With the integration of life cycle considerations in this early concept phase of automotive development, a high influence on the definition of properties and the development of vehicle technologies can be expected. As an example, Fig. 6 shows a comparison of dissimilar automotive car bodies with different materials.

Figure 6 Comparison of automotive body types with different materials. 1: standard steel body (Volkswagen Golf [9]), 2: aluminum space frame technology with carbon fiber components (Audi R8 e-tron [10]), 3: prototype of a wood frame vehicle body (Nios [11])

Obviously, due to different physical and technical properties, different materials lead to different bodywork structures, challenging design, construction, simulation and verification. Exemplary, Fig. 7 illustrates the influence of the defined geometry of a longitudinal beam on the closed chain dimension in a schematic front end of a car.

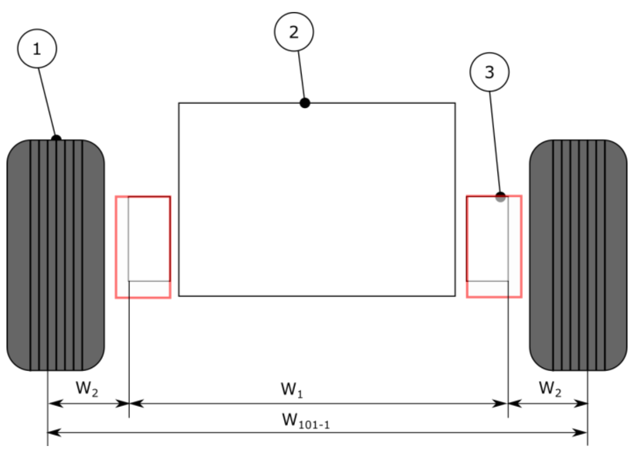

Figure 7 Schematic front end of a car. 1: tire, 2: engine, 3: longitudinal beams. W_1: distance between longitudinal beams, W_2: wheel contact distance to longitudinal beam, $W_{101\text{-}1}$: track width

The track width $W_{101\text{-}1}$ is an important dimension in the vehicle, that influences packaging, comfort and the vehicle driving dynamics behavior. $W_{101\text{-}1}$ is influenced by the outer dimensions of the tire, which (among others) affects the wheel contact distance to the longitudinal beam, W_2. The distance W_2 depends on chassis dimensions and the suspension system. As a simplification, it is considered as constant in this example. With changing dimensions of the longitudinal beam (3, transferring from the grey box to the red box), the wheel may change its position, which influences the track width $W_{101\text{-}1}$. Geometrical changes may occur with the use of alternative materials in the car body, due to different physical and technical properties. As those basic geometries are defined in the concept phase, this influence needs to be considered in the same phase. Especially alternative materials show different mechanical, structural and durability-related behavior, which requires more space for the components. Exemplary, aluminum space frame design is characterized by larger cross sections and different connection technologies than traditional bodywork made of steel. Carbon fiber or even composite made of sustainable material, e.g. wood based fibers and composites require more packaging space and new design solutions to tap their potential. These aspects have to be considered in the early layout phases of new cars. The goal is to find new solutions that provide advantageous characteristics in terms of life cycle related considerations, but that are also able to fulfil the long list of technological factors, e.g. load, stiffness, durability, eigenfrequency behavior, corrosion, predictability and costs.

Today, life cycle considerations, e.g. targeting the selection of proper materials for the required parts and components, typically start after the conceptual development, parallel and in conjunction with the delivery and supplier selection process. The term "supplier" includes all economic units which supply industrial intermediate products or provide corresponding services in the course of an inter-company work within the value chain. Suppliers are often structured according to the cooperation form with the OEMs. Typical classifications are research and development (R&D) suppliers, production suppliers, or development and production suppliers. Another classification addresses the positions of a supplier in the value chain (Tier 0.5, Tier 1, Tier 2, etc.) [12]. In case of full-vehicle development, suppliers are increasingly deeply involved throughout the entire process chain, and even in the concept phase. In this way, supplier industry has a considerable effect on sustainable evaluation and life cycle assessment. In case of the exemplary mentioned bodywork design process, suppliers are integrated into packaging development and evaluation, functional layout and, of course production engineering of the delivered modules and components. In this way, suppliers play an important role as innovators, e.g. in the selection process of alternative technologies.

As previously illustrated, the physical vehicle base architecture is already defined in the initial concept phase. Changes, which are made in later process steps that have impact on the vehicle architecture, lead to increased costs and extend development time. This means, that the basic architectural spatial topology should remain untouched when finishing the concept phase. By this, especially components with a high spatial consumption require their life cycle considerations made in early stages of the development, because a modification is not possible anymore at later process phases.

As a conclusion, focusing on the design engineer's requirements in the concept phase, a need of information support can be detected, addressing possible changes and influences with the integration of innovative materials and sustainable technologies. Therefore, the following section introduces an approach to providing relevant information.

4 APPROACH TO PROVIDING RELEVANT INFORMATION IN THE EARLY CONCEPT PHASE

The approach targets a comprehensive consideration of influencing aspects for conceptual car design and layout. As a basis, influences in the basic concept of new technologies are identified and evaluated. Information about materials and technologies are sampled and clustered under consideration of their planned application. Focusing on the engineer's requirements, technical specifications need to be addressed, including influences on the production phase. Besides that, life cycle-relevant key indicators (e.g. cumulative energy demand or resulting CO_2 equivalent emissions for materials production) are calculated and brought into the decision processes. Especially in case of new (sustainable) technologies or material, a possible application has to be planned carefully. This includes risk analysis, cost calculation, and technology integration. Examples are information regarding stiffness and safety-relevant specifications (e.g. splinter behavior in the case of crash), or NVH[2]-behavior.

In state-of-the-art vehicle development, much of this information is provided by former similar developments and/or experiences. With the integration of novel technologies, the missing experience can only be compensated by a collection of relevant information from different R&D departments and the provision of a comprehensive database. With this database, the influence of material specifications on the component design needs to be evaluated, since the concept designer rather needs information concerning the basic geometry than technical specifications. This task is elaborated by pre-development departments, where developments and tests of technologies are carried out.

Component design and development is often carried out by or with subcontractors and suppliers. Since this process usually starts after the concept phase (see Fig. 1), information about the production process of parts from suppliers is not available during the concept phase. To meet this challenge, there is a need for closer collaboration between the engineers and the suppliers during the concept phase.

5 CONCLUSION

During the last decades, automotive development has been characterized significantly by a growing share of intelligent components, increasing technical complexity of vehicles and vehicle modules and steadily increasing model ranges. Furthermore, there is a need to focus even more on future challenges regarding sustainability. Besides the reduction of impacts from the use-phase of a car, the phase of production and end of life gains in importance. This trend is driven by a steadily increasing number of legislative boundary conditions and directives concerning the use, recovery and re-use of materials in the vehicle, but also by an increasing awareness of the customer. To meet those trends, the present paper has discussed an integration of novel sustainable materials and technologies in state of the art-vehicle development processes, and provided an approach that supports the implementation and evaluation during early development stages.

The main decisions in the development of a new vehicle or technology are made within a described four-step development process in the early stage of vehicle development. Focusing on the design engineer's requirements in the concept phase, a need for information support can be detected, addressing possible changes and influencing aspects that stem from the integration of innovative materials and sustainable technologies. An approach to answer this need includes the provision of material data, together with the evaluation of influencing factors on vehicle packaging and geometry, as well as a closer collaboration with supplier industry in vehicle conception.

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