Title:
Sustainability Engineering Support for Automotive Development

Authors:
Mario Hirz, mario.hirz@tugraz.at, Graz University of Technology

Keywords:
Sustainability, automotive development, life-cycle assessment, engineering support

DOI: 10.14733/cadconfP.2024.254-258

Introduction

The automotive industry is challenged by societal, legislative, and market-related boundary conditions that target more sustainable products and solutions. As a consequence, the entire industry sector is in a transition that will force a reduction in environmental impact. This covers a change of propulsion technology towards electrification and alternative fuels, as well as the use of dedicated materials, production technologies, and recycling processes to reduce resource demand and environmental pollution. The dependencies and interactions of design decision-related factors are complex, as aspects of the entire product life cycle have to be considered. This includes the selection of materials, related manufacturing processes, different effects of the vehicle's use phase, and recycling and disposal. In this way, the layout and design process is influenced not only by technological and economic aspects but also by sustainability-related factors from a holistic point of view. In this context, the present article introduces an approach to sustainability engineering support, which provides comprehensive information about factors that influence sustainability for engineers and decision-makers throughout vehicle development. In this way, experts are able to make design decisions based on a broader data basis, considering technical, economic, and sustainability-related aspects. The approach is based on a provision of relevant information in parallel to the different steps of vehicle development. This covers requirements engineering, concept development, series development, testing and verification. In this way, information is supplied by processing the desired data and material to the corresponding experts in the different sequences of product development.

Sustainability-related factors in automotive development

The consideration of ecological factors plays an increasingly important role in the automotive industry. This includes the reduction of exhaust emissions to decrease pollution and climate warming, but also the demand of land-, energy-, water- and other resources [1]. Global climate change, resource scarcity and growing pressure from relevant stakeholders have stimulated the automotive industry to integrate sustainability considerations into their business activities. These reflections have to start already in the early sections of product development, since in these phases up to 80 % of product characteristics, costs and the majority of environmental impacts are determined.

Currently, sustainable automotive product development focuses on a number of directives to ensure compliance with material prohibitions and environmental regulations in vehicle production and end of life phases. One example of legal conditions includes the ELV directive of the European Union, which addresses the end-of-life treatment of vehicles [2]. Another focus of the legislation lies in the reduction of greenhouse gas emissions and pollutants during operation. A selection of related legal conditions is described in [3]. One measure to reduce the greenhouse gas emission impact of cars is focused on mass reduction, which can result in lower driving resistances and thus lower fuel-, respectively, energy demand during driving. In this way, different lightweight materials come into use, e.g., high-strength alloys, light metal, fiber-reinforced plastics, and multi-material construction, but the resources and energy demand of materials production, processing, and vehicle manufacturing might be increased for these alternative technologies.

For example, the use of aluminum has potential to reduce the body mass about 30% in comparison to steel-made car bodies. Moreover, the use of carbon-fiber reinforced plastic (CFRP) material has a weight reduction potential of about 50%. But the efforts for production of these lightweight materials is significantly higher than for steel. Figure 1 shows results of a study that investigated the impact of different body materials and their production technologies on the CO_2 equivalents of bodywork production. The study is based on [4], which investigated the greenhouse gas emission impact of different influencing factors on CFRP production, and enhanced with data from an actual study for investigation of body materials for a midsize class car. The relatively large variation of CO_2 impact for CFRP is based on the fact, that different production technologies are taken under account. The lower limits indicate future technologies and the use of electric energy with a low CO_2 impact. The upper limits indicate today's production technologies and the use of average CO_2 footprint of electricity production in industrial countries. It has to be stated, that a relevant impact on the greenhouse gas emissions is also caused by the different technologies for recycling. Steel and aluminum can be supplied to recycling processes in an efficient way on industrial scale, whereby CFRP is very difficult to recycle. As a result, the diagram shows that a reduction of body weight by technology change is connected to significantly higher greenhouse gas impact in production. In this way it is highlighted that the entire lifecycle of the product must be considered when selecting a specific technology in product development.

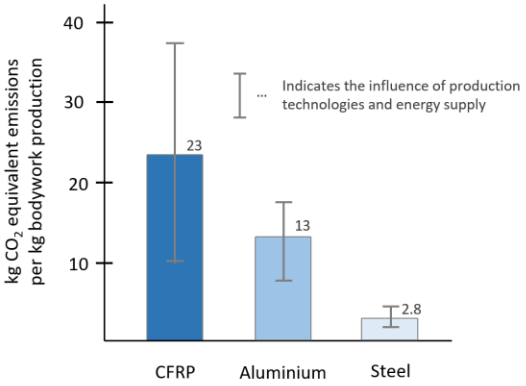

Fig. 1: Production-based CO_2 equivalent emissions of selected automotive bodywork materials.

Besides body weight and production-related greenhouse gas impact, economic and technological factors are also to be considered in decision-making processes. The selection of car body materials includes investment costs for production facilities and variable costs for raw materials, body panels, parts manufacturing, joining technology, corrosion protection, and painting. Considering these factors, steel bodies show economic advantages in case of larger production sizes, typically above about 100.000 pieces per year. Aluminum space frame design enables the introduction of relatively simple components, which reduces investment costs but increases costs for assembly and joining techniques. Carbon fiber provides advantageous physical behavior, but this technology is the most expensive one for automotive body design by far and has the highest CO_2-impact of production. As a consequence, it has to be investigated in detail if a lightweight technology is advantageous in view of total life cycle footprint and economic viewpoints.

The example demonstrates the essential importance of an overall consideration of life-cycle-related aspects in the product development process. In this context, the integration of eco-design approaches and strategies for sustainable product development can contribute significantly to the reduction of resource demand and increase the efficiency of material cycles facing future challenges in

Proceedings of CAD'24, Eger, Hungary, July 8-10, 2024, 254-258

sustainable production. During vehicle conception- and design processes, several aspects have to be considered: Careful use of resources plays a crucial role in reaching sustainability goals. This includes recycling-related product development that forces the use of recycled materials. If possible, renewable (e.g., plant-based) materials should be taken into account in design decisions. Consideration of guidelines for materials marking and disassembling processes can support recycling, not only for complex components such as battery systems but also for simple parts. Heavy metals should be reduced as much as possible to lower environmental impact and to increase the re-usability of recycled metals.

Sustainability engineering support

The approach presented in this article, capable of effectively supporting design engineers and decision-makers in their work, is based on the direct integration of a data-based tool into the design process. In this way, experts are supported by fundamental and comprehensive information about sustainability-related characteristics of their design decisions in real-time. The method supports holistic evaluation of solutions, which not only covers the traditional technological and economic aspects but also involves relevant data on environmental impact. Figure 2 shows the architecture of the approach in the example of automotive bodywork development, but the methodology can, of course, be applied to different other systems, too. In the exemplarily shown bodywork development process, the computer-aided design (CAD) model plays a central role because the CAD process defines geometrical shapes and materials as well as manufacturing-related aspects. Thereby, the CAD process is closely interlinked with parallel engineering processes, e.g., packaging and ergonomics, body structure development and crash simulation, aerodynamics optimization, and manufacturing-related investigations [5]. In the course of vehicle development, the CAD model includes both the generation and supply of geometrical data and characteristic parameters to adjacent processes, as well as processing information from simulation and verification for enhancement of the model in the course of circular, recursive processes. In this way, the sustainability engineering support is connected to the CAD process, because of its central role in product development. This strategy enables processing of information via the design stage to other development processes.

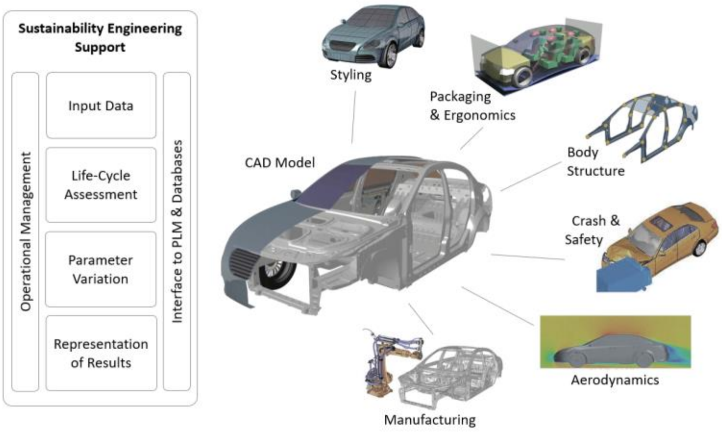

Fig. 2: Architecture of the sustainability engineering support approach on the example of bodywork development.

The sustainability engineering support is composed of four main modules, plus operational process management and interfaces to product lifecycle management (PLM) and different databases. The four main modules include an interface for data definition, a so-called input data module, a comprehensive section for life-cycle assessment-based analysis and investigation, a section that enables variant studies and optimization by parameter variation as well, and finally, a section for representation of the results. The tool can be applied throughout product development by integrating it into the different phases of automotive development to provide tailored information for each step of product creation. This covers the elaboration of product characteristics during requirements definition, the concept phase, but also detailed module- and component development as well as production development and supplier integration.

In an exemplarily realization, the sustainable engineering support is integrated into a commercial CAD software. Figure 3 shows this integration by use of specified toolbars that provide different functions. So, the design engineers have easy access to the tool directly in the used CAD software and can perform sustainability evaluation during their design work. In Figure 3, the application of the tool is exemplarily shown for the development of a sheet metal part, which represent one component of a bodywork section. The part is made of a standard steel with specific material characteristics, that influence geometrical shape, mass and joining technologies. As an alternative, high-strength steel might be an option, which allows lightweight design, but that comes with higher effort in materials provision and processing, and consequently higher energy demand and CO_2 equivalent emissions in production. In this example, the sustainability engineering support tool provides a bunch of information to the design engineers, which includes product characteristics as well as environmentally-related footprint of production and during the use phase, e.g., by reduced energy consumption of the car because of less vehicle mass. Based on this information, the expert can select the optimal variant for the specific use case.

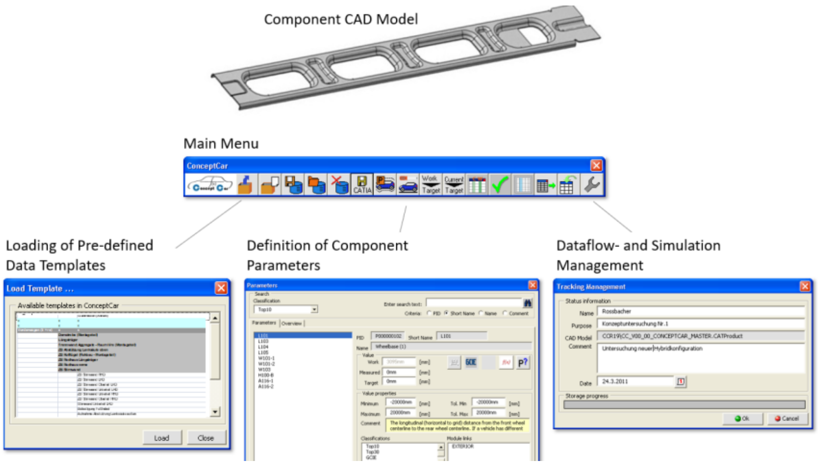

Fig. 3: Exemplary application of the sustainability engineering support tool for the development of a sheet metal part.

The example of the application of the tool based on a single sheet metal part is focused on the material selection within tight boundary conditions because an overall decision for steel bodywork has been made in a previous process step. Of course, the approach of sustainability engineering support can also be applied on the system level, e.g., in the course of concept development. In that case, the entire vehicle bodywork would be assessed in view of potential design solutions and material selections. In the case of a full-aluminum body, the exemplarily shown component in Figure 3 might have a different geometrical shape, which has to be assessed accordingly in view of its impact under consideration of sustainability criteria. Another option is to make the bodywork of CFRP, which would lead to an even more different design solution that could make the exemplary component obsolete. In that case, sustainability-related considerations would be conducted for the entire car body design and compared with other car body solutions, e.g., steel body and aluminum body.

Proceedings of CAD'24, Eger, Hungary, July 8-10, 2024, 254-258

Conclusions:

Increasing demands on mobility- and transportation sectors to lower their environmental impact challenge the automotive industry by forcing a transition of vehicle- and propulsion technologies, as well as the introduction of new services and business models. A central role in this evolution is the development of new vehicle concepts and technologies under careful consideration of sustainability-related aspects. In view of automotive product development, the design of new technologies and vehicle concepts requires a deep integration of methods and tools into the development processes, which enables the evaluation of environmental impact. This starts with the definition of product specifications, covers early vehicle layout and conception, and influences detailed product development as well as manufacturing engineering.

With the target to fulfill the high demands on data and knowledge provision throughout the entire vehicle development process, a new approach to sustainability engineering support is introduced. The approach includes the sequences of data provision, data processing and the representation of results in parallel to different engineering workflows. A direct integration into the applied commercial computer-aided design software supports the intuitive handling of the tool and motivates involved engineers to use it in parallel to their engineering tasks. Effective assessment of design variants is supported by holistic life-cycle analysis under consideration of materials, manufacturing technologies, effects of usage as well as consideration of recycling processes. In this way, experts and decision-makers are supported to find the optimal solution for product specification as well as for detailed product development, which supports the creation of new and more sustainable vehicle concepts and technologies to reduce the environmental impact of the transportation sector.

References:

[1] Zapf M.; Pengg H.; Bütler T.; Bach C.; Weindl C., Kosteneffiziente und Nachhaltige Automobile, Springer Verlag Berlin/Heidelberg, Germany, 2021; https://doi.org/10.1007/978-3-658-33251-8

[2] ELV Directive 2000/53/EC of the European Parliament and of the Council of 18th September 2000 on end-of-life vehicles. L 269 - 43, Brussels

[3] UNECE R101, Regulation Nr. 101 of the Economic Commission for Europe United Nations economic Commission for Europe (UN/ECE), 2007, Brussels

[4] Schnöll H.P.; Brunner H.; Zottler M.; Hirz M., Ramsauer Ch., "CO2 reduction potential of CFRP bodywork concepts considering production and in-use phase", 7th International Scientific Conference Management of Technology Step to Sustainable Production, Croatia, Brela, 2015, https://www.researchgate.net/publication/279526593_CO2_Reduction_Potential_of_CFRP-Bodywork_Concepts_Considering_Production_and_In-Use_Phase#fullTextFileContent

[5] Stadler S.; Hirz M., "A knowledge-based framework for integration of computer-aided styling and computer-aided engineering, Journal Computer-Aided Design and Applications 13(4), 558 - 569, 2016. https://doi.org/10.1080/16864360.2015.1131552