Chapter 27
Sustainable Mobility

Alain Biahmou

Abstract Considering sustainable mobility, the electrical powertrain of road vehicles has an increasingly significant role. Besides delivering benefits in air and noise pollution, it encompasses huge challenges in practical usability, reliability and total costs of ownership combined with novel models of exploitation. Therefore, sustainable mobility is a typical field of application for Concurrent Engineering. The design of electric vehicles requires bringing components from different domains together in order to integrate them in the overall vehicle concept. The domains involved utilize their own specific methods, processes as well as software tools in order to create partial models of an overall system. This leads to dependencies between several disciplines and, therefore, to the need to track the impact of model interactions to avoid data inconsistency as well as design errors. The focus of this paper lies on the project "Process Chain Battery Module" that has been conducted at EDAG Engineering AG to capture the challenges related to the electrical battery when designing electric vehicles. Thermal management, which is one of the critical challenges to be tackled in the area of electro mobility, is discussed and solution approaches are presented. Requirements are defined and linked with functional analysis as well as geometrical, behavioral and FEM models. Thus, changes can be traced from each partial model back to the initial requirements. Interface management between the domains and partial models is realized to enable an analysis of the entire vehicle. Complex simulations are performed in a very early stage of development in order to determine the range of an e-vehicle model (EDAG Light Car).

Keywords Sustainability · Systems engineering · Mechatronics · Battery simulation · Thermal management

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J. Stjepandić et al. (eds.), *Concurrent Engineering in the 21st Century*,
DOI 10.1007/978-3-319-13776-6_27

27.1 Introduction

Most transport vehicles are powered by an internal combustion engine which is the most widespread power supply for cars nowadays. Although the development of combustion engines may bear further improvement potential, it is important to remark that using combustion engines is related to side effects such as the emission of carbon dioxide and noise emissions that contribute to environmental pollution. Furthermore, the increasing scarcity of fossil fuels and the more and more stringent laws for environmental protection lead to the necessity of developing alternative solutions for powering cars.

The analyses that have been performed during the project described in this chapter are focused on car concepts, especially the powering of a car with a battery, since it is the most important component of electric cars. The battery significantly influences the maximum reachable distance, weight, power, price and life duration of an electric car [1].

The powertrain of an electric vehicle differentiates itself from the powertrain of conventional cars. Electric motors can start from stop position and operate efficiently over a wide speed range. Therefore, it is not necessary to integrate a clutch in the vehicle design, as it is the case in internal combustion engine vehicles. For hybrid vehicles, the internal combustion engine is to be coupled with the electric motor; this makes the transmission more complex [2].

The electric car is the most popular alternative solution to cars powered by combustion engines. The battery technology and the electrified powertrain are the major innovations of electric cars compared to conventional cars powered by a combustion engine. Existing concepts of electrical powertrains are based either on a battery as single power supply, hybrid electric power supply as well as micro fuel cells. Cars powered by a battery are characterized by a limited overall range and a relatively long battery recharging time. Besides, additional systems inside the car such as cooling devices, but also external factors such as low temperatures and the shape of the terrain may significantly reduce the maximum reachable distance [1].

In fact, the driving range and the battery power are the most important parameters of an electric car from a customer perspective, even though considerations regarding the infrastructure (e.g., power supply stations) also play an important role. The vehicle price and the driving experience are certainly predominant factors; however, the vehicle price is directly impacted by the price of battery packs. In order to significantly increasing the driving range, the number of battery packs and, therefore, the total car costs are also to be increased. To decouple the relationship between driving range and vehicle costs, a study proposes inductively coupled power transfer (ICPT) as a potential solution [3]. ICPT is a technique that can transfer power without physical connection between vehicle and energy source. The objective of this approach consists in increasing the range of an electric vehicle without substantial impact on the weight or cost of the vehicle. The power track is to be located into a road surface, while the vehicle receives the induced energy through an integrated Pick-up [3]. The vehicle is to be directly powered with electromagnetic inductive energy, which alternatively can be used to charge the vehicle battery [4].

Battery cost and the limited range of electric vehicles also can be improved using a range extender, which consists of an on-board fuel converter that converts a liquid fuel, such as gasoline, into electrical energy whilst the vehicle is driving. This approach has been demonstrated with a compact class vehicle [5]. Although the objective of carbon-free emission cannot be reached while the range extender is contributing to the drive, emissions can be reduced, in particular for short runs, improving the usability dramatically.

The difference between a conventional and an electrical car is not limited to their powertrains, since the development of electric cars opens various opportunities for new concepts, like using singular electro motors for driving each wheel or very complex energy business models which describe new interaction models of power providers with owners of electric cars. Such a business model may consist of owners of electrical cars buying or selling electricity back to an energy provider not only for stabilizing the current network but also to make profit, depending on the day time and the need. Besides, the intensive use of electric cars may lead to a modification of the architecture of current networks as well as the adaption of cities, which would have to integrate a suitable infrastructure, for instance load stations.

It is important to get a whole car perspective in order to gather the mutual influence of relevant parameters [6]. Sharing of status information as well as technological data has to be observed for realizing an efficient parallelization of processes, which is a core principle of concurrent engineering.

In fact, the questions that have drawn the attention concern determining an efficient way of working when it comes to develop electrical vehicles. Since electric cars concepts are different from conventional ones, tools and methods as well as interfaces between the different disciplines involved might also be different or at least imply additional facts that are to be taken into account to keep the cutting-edge advantage of EDAG Engineering AG as one of leading engineering companies in Germany [7].

This chapter continues with a brief introduction to sustainability (Sect. 27.2), whereby its perception in the automobile industry is emphasized. Selected research works that contribute to sustainability are highlighted (Sect. 27.3). A case study is addressed (Sect. 27.4), in which Systems Engineering has been applied in order to realize the technical design of an electric car battery, the most important additional module of an hybrid or electric car, contributing therefore to sustainability. The case study is realized following the RFLP methodology. That approach describes developing complex products by starting with a requirements model, then deriving a functional model, from which a logical and a physical model can be created. Discussion and reflection to concurrent engineering is made and some perspectives for the case study are mentioned (Sect. 27.5), followed by conclusions and outlook in Sect. 27.6.

27.2 Sustainability in Car Development

Although the term sustainability sounds like an invention of the two past decades, it has been first used by Hans Carl von Carlowitz in his book titled "Sylvicultura Oeconomica. Die Naturmäßige Anweisung zur Wilden Baum-Zucht", published 1713 in Germany. The term sustainability has gained a more particular attention since the 1992 Rio Earth Summit with the motto sustainable development. The core idea has consisted of preserving natural resources for maintaining the quality of life of future generations [8].

Sustainable vehicle design process, therefore, should include criteria such as technical performance, design, vehicle production, cost, quality and so on. In order to achieve greater benefits in terms of minimized environmental load and cost, sustainable design principles are to be integrated into the development process [9].

In the automotive industry, sustainability has evolved from its initial understanding as ecological development and production of vehicles to a holistic concept, which integrates the reduction of pollution and resource consumption, the quality of life of the population as well as economic success of enterprises. Nowadays, the original equipment manufacturer (OEMs) are not only interested in fulfilling legal requirements over environment protection, since sustainability has become a purchasing argument. Furthermore, corporate sustainability is an important factor for business success, because investors can make their decision according to sustainability rankings which are provide for instance by the Dow Jones sustainability index (DJSI).

Enterprises have identified many factors which contribute to sustainability, such as manufacturing processes, the optimization of combustion engines, alternative engines, materials and vehicle architectures [10].

27.2.1 Manufacturing Processes

Some works have presented technologies that enable the manufacturing of materials with specific characteristics, such as a light weight, leading to reduced resource consumption. Other research approaches focus on manufacturing material with important chemical properties.

Bruckmeier and Wellnitz present a pultrusion technology that enables the manufacturing of profiles with specific short-term mechanical properties such as stiffness, strength, elongation to failure, shear strength and impact resistance. Pultrusion is a continuous method of manufacturing various reinforced plastic shapes of complex cross sections. The elaborated fiber glass-reinforced pultruded polyurethane may help reducing wall thickness and, therefore, component weight, even though the knowledge of its long-term mechanical behavior is limited [11].

Cannon et al. [12] have presented a technology for creating a microstructure on the surface of parts in order to provide them with a superhydrophobicity ability.

Superhydrophobicity is the ability of some surfaces to imitate the water repellency of lotus leaf. Superhydrophobic surfaces can also exhibit "self-cleaning" properties, which are useful for automobiles because droplets that roll off of the surface carry away particles that are larger than microstructure spacing. The materials that can be microstructured by the approach presented include stainless steels, tool steel, nickel, titanium, copper and carbide steels.

Volatile organic compounds (VOC) are organic chemicals that are able to evaporate and, therefore, enter and pollute the air. They are emitted by cars even at switch-off state and enter the surrounding air. Due to the health risks associated with VOCs, limit values for VOC emissions have been formulated in guidelines such as 2004/42/EG/ by different institutions worldwide (e.g., EU, AgBB, AFS-SET, California Department of Public Health). The objective of some research work consists of reducing VOC emissions. A research approach following that principle is a waterborne pretreatment technology for Direct Glazing, to be applied in Automotive [13].

27.2.2 Enhancing Sustainability with Optimized and Alternative Energy Sources

Many contributions to sustainability are dealing with the optimization of fuels to reduce environment pollution, while others are proposing alternative energy options to replace fossil fuels with renewable energy sources. Well-known examples are Bio-fuels and electricity produced by solar, wind and geothermal energy, which are largely used nowadays.

Batteries are the energy source that have been mentioned most in the context of electric vehicles. The requirements of EV and hybrid electrical vehicles are high specific power, high specific energy, and high charge acceptance rate for recharging and regenerative braking, long calendar and cycle life [2].

Although many research works have focused on improving battery properties, battery development has not yet reached the stage which would be necessary to power a car on very long ranges. A serious alternative for battery is the fuel cell.

The use of methanol in methanol-to-gasoline, -diesel and -kerosene processes to synthesize drop-in fuels that can fully decarbonize the known forms of transport have been discussed. These discussions have been made on the assumption that the vehicles must not be changed significantly. Furthermore, methanol has been presented as an interesting transport fuel for spark-ignition (SI) engines, because it is synthesized from sustainable sources. The configuration of ternary blends out of the three components methanol, ethanol and gasoline as well as using methanol consuming fuel cells for range extended electric vehicles have been analyzed [14].

The optimization of existing fuels goes beyond the research of substances that might be blended. The compositions of blends are subject of further studies. Bunting et al. have evaluated diesel range fuels using a homogeneous charge compression ignition (HCCI) engine. The analysis has included bio-diesel blends with differences like oxygen content, iodine number, cetane, boiling point distribution, chemical composition, and contained nitrogen. Fuel and engine control variables are used as input variables of the experiment, while emissions (NOx-Nitrogen oxide, smoke), fuel economy (ISFC) and control information (intake temperature) are output variables. Fuel with lower nitrogen and oxygen, lower cetane and lower aromatics offered the best results [15].

The most promising option for realizing a zero-emission objective is to use a fuel cell, which is an electrochemical engine. Unlike a combustion engine, the fuel does not burn; it reacts with air. In order to carry out this process, hydrogen, methanol, ethanol, natural gas, as well as liquefied petroleum gas, are often used as fuels. The most relevant fuel cell technologies are molten carbonate (also known as direct fuel cell—DFC), proton exchange membrane (PEM) and solid oxide. Additional to electricity, DFC produces heat as by-product, PEM and solid oxide technology generate water and heat as waste products [16].

An alternative fuel that offers carbon-free transport is, therefore, hydrogen since its reaction with oxygen provides water. Some OEMs are interested in using hydrogen fuel cell (H2FC) that produce electrical energy to drive an electromotor that in turn propels the vehicle. An alternative approach consists of using an internal combustion engine (H2ICE), which uses hydrogen as fuel. Using H2FC helps obtaining a higher efficiency, since the efficiency of the H2ICE approach is limited by the heat phases that are included in the engine cycles. On the other hand, cost and weight of H2ICEs are more advantageous and they can run on fuel of less good quality (e.g., impure fuels). A comparison of both systems emphasizes the negative impact of the mass of fuel cells on the whole vehicle mass, but also the fact that not only isolated factors such as thermodynamic efficiency and power density are to be taken into account when comparing vehicles. All relevant system parameters are to be considered [17].

There are already commercial hydrogen fueling stations using the hydrogen that has been produced either with geothermal power by stripping hydrogen out of water molecules or with wind power [16]. Although hydrogen—to power the fuel cells—is appropriate as alternative energy option, one of its short-comings is its small volumetric energy density, which complicates its storage significantly and, therefore, its transport, distribution and usage in series-production vehicles. This has led manufacturers to using alternatives such as solar-powered hydrogen stations or the application of technologies on-board to extract hydrogen out of other substances and provide it to fuel cells. Thus disadvantages of providing hydrogen to vehicles can be solved using methanol [14, 16].

However, the reformer (hardware) used to reach this objective can be very heavy. It can also produce a certain amount of carbon dioxide as by-product and, therefore, would impact the energy balance. Additionally, ammonia can be used as alternative fuel for internal combustion engines, since ammonia is made out of a large fraction of hydrogen. Ammonia can be liquefied easily and a suitable synthesis technology is well established. Tests have been conducted using an auto-thermal cracker (ATC) to dissociate hydrogen and nitrogen from ammonia and provide them to a single-cylinder engine. The results have shown that a stable combustion can be achieved [18].

An objective of many manufacturers is making the fuel cells smaller, lighter and inexpensive. The advantage of a fuel cell over a battery is that the potency of batteries may decrease. In contrary, fuel cells keep producing power as long as the fuel and oxidant supplies are maintained. Another research approach is the use of microbial fuel cells (MFC). This technology consists of generating electricity out of organic material available in waste-water. Therefore, biomass can be used to generate hydrogen and ethanol that can be used to produce electricity for powering an engine. Advantages of using MFCs go beyond the reduction of emissions, because the cleaned water may be used for other purposes. The MFC technology for power generation is certainly not yet mature for use in serial vehicles, but it could become a serious option in the future [16].

A rather new method for generating hydrogen for fuel cells consists of using algae, from which sulfur is separated and hydrogen is generated. This method is still explored in prototypes and is not yet appropriate for an industrial deployment.

An economic and environmental comparison has been performed on conventional, hybrid, electric, H2FC, hydrogen-fueled ICE and ammonia-to-hydrogen vehicles. The comparison has shown that hybrid and electric vehicles are more advantageous than the others. Electric vehicles may have a better balance than hybrids depending on the conditions of electricity generation, for instance when it is produced from renewable energy sources [19].

27.2.3 Enhancing Sustainability with Materials

Some contributions to sustainability consist of optimizing properties of existing materials [20], but also of substituting them with alternative ones (e.g., biologically degradable materials). Besides, optimization can be achieved through the modification of the structure of a technical system. Many studies following that approach are based on lightweight engineering, which may help achieving a very high material and energy efficiency. Composite materials generally are used for that purpose in the mobility industry.

Composite structures can be used in the aerospace industry to reduce weight and, therefore, fuel consumption while simultaneously improving the structure of an aircraft. Basic structural elements such as plates and shells are often used in airplane structures to absorb vibration [21].

A further study explores a combination of lightweight design of a seat shell developed with respect to the holistic design approach of the so-called “Dresdner Modell” with a manufacturing process for high-volume production of textile-reinforced thermoplastic materials. A prospective resource-oriented product assessment of the seat shell is performed and its lifecycle (in fact energy and material inputs of the different lifecycle phases) is compared with that of a corresponding steel seat based on resource demand. The results confirm that the lightweight seat shell can significantly reduce resource consumption [22].

Further studies have focused on applying lightweight design to obtain a mass reduction, whereby several design parameters are varied and simulated in order to search and manufacture a suitable, totally new material. Examples have consisted of running finite element analysis (FEA) and optimizations to search suitable materials, configuration and topology of a side door [23].

A similar study follows the objective of creating a new composite material [24].

27.2.4 Enhancing Sustainability with Optimized and Alternative Drive Systems

Due to the obstacles in producing zero-emission vehicles on a large scale, the reaction of OEMs has been to elaborate intermediate solutions, which are hybrid vehicles. These generally combine a gasoline engine with electric motors. Hybrid vehicles may be classified in serial, parallel, power split and combined hybrids. Serial hybrids use a combustion engine that is coupled to a generator to provide energy to the driving electromotor and simultaneously to the battery. Parallel hybrids combine a combustion engine with one or more electrical motors, whereby both motors can interact, for instance to provide the necessary power when driving up- and downhill or for recharging the battery. This hybrid type has the highest potential to reduce fuel consumption. Power split hybrids enable a separation of the mechanical power to be transmitted into a mechanical and an electrical path.

A particular case is the combined hybrid, which enables both serial and parallel operating. Depending on their degree of hybridization, there are micro, mild, full and plug-in hybrids. The latter additionally enable external battery recharging requiring a higher battery capacity and, therefore, an increase in costs. Nevertheless plug-in hybrids might be a transitional solution to the electric vehicle [25]. While the first hybrid vehicles were equipped with a battery for powering the electromotor, latter hybrid cars combine a battery and fuel cells [16].

Shortcomings of hybrid vehicle are due to the fact that the system is more complex since two motors are integrated. This requires more skills for maintenance than for conventional cars. However, hybrid vehicles can substantially reduce emissions in urban traffic.

Rotatory piston machines (RPM), which transform stored chemical or physical energy into rotary motion or vice versa, are presented in a further study. RPM technology may offer a greater power density and a corresponding increase in efficiency, compared to customary aggregates. Additional benefits are a simultaneous reduction in built space volume and weight of the engine. An RPM turns slower than a conventional engine of the same power, for example, a standard reciprocating piston machine or a Wankel engine. This impacts the combustion process and, therefore, the quality and quantity of the exhaust gases and pollutant emissions [26].

27.2.5 Summary Evaluation

The technologies presented above are very interesting and even though some research work seems fundamental and mono-disciplinary, it is noticeable that the results presented imply concurrent engineering thinking. If for some works, other disciplines come in with evaluation, comparison and testing, for other one, the are part of the initial concepts, especially when innovative concepts are to be investigated. In these cases, the infrastructure for testing also must be developed parallel to the core innovation, for instance the material or the fuel that should help enhancing sustainability.

The works that have been performed to enhance sustainability with specific manufacturing processes show a cooperation at less between the disciplines manufacturing engineering, material engineering and nano- and high-precision technologies in chemistry. The same, works that investigate alternative energy sources often are based on a multidisciplinary approach, for instance when it comes to determine the impact of fuel cell mass on the whole vehicle, or when it comes to develop models for transporting and distributing hydrogen. Furthermore, it is assumed that concurrent engineering plays an important role in projects groups that have to develop concepts involving biological knowledge, chemistry and mechanical engineering. This is the case when for instance, fuel is to be gained out of algae or any organic material.

In the practice, car makers already are exploring the federation of many factors that enhance sustainability. For instance, combining conventional light-weight design with the substitution of steel parts by composites structures as well as using an hybrid propulsion. However, this way of thinking should be emphasized and the

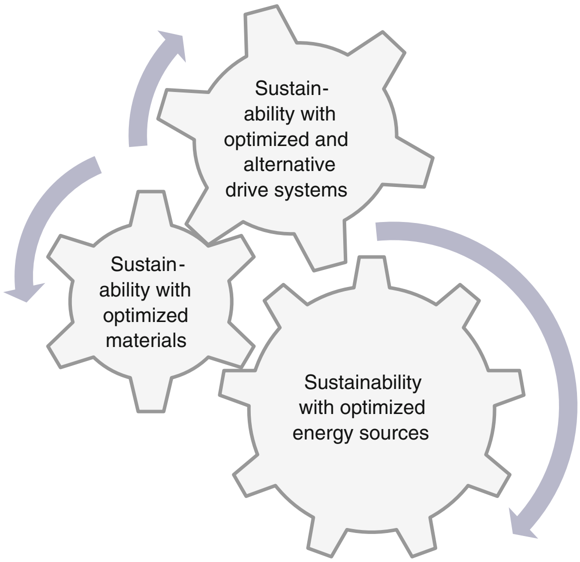


Fig. 27.1 Different ways to realize sustainability, which are considered in this work

impact of the different approaches for enhancing sustainability should be assessed in order to ensure synergy and strategic orientation of the multitude of research works that are currently performed in academic and industrial institutions. It is a matter of evidence that the different approaches can impact each other as shown in Fig. 27.1.

27.3 The Generic Car Development Processes

Even though the principles of driving as well as the architectures of cars have not significantly changed in the past decades, car development processes have been subject to significant modifications [27]. The components to be designed have become very complex and have integrated functions which imply knowledge in different disciplines. Therefore, many disciplines develop components, a process which in the past used to be aimed at charging a single engineer.

In order to determine the impact that electric cars may have on existing processes, it is important to draw a picture of product development processes as well as tools that are involved. First of all, product strategy defines a profile of a new car according to the relevant brand profile, which itself is intended to impact the long-term perception of customers. A specific car profile provides details of factors such as segment, the targeted population as well as characteristics such as level of comfort, functionality, size and so on.

The next development phase is the feasibility study that includes economical as well as technical feasibility based on a target framework. The latter integrates essential factors such as weight, variants, technical function, equipment, innovation, production and assembly, quality, services and administration. These studies consist of determining whether the envisioned car project is to be conducted or not [28].

Three-dimensional virtual and real prototypes are involved in the concept phase in order to check whether the car to be developed will meet the requirements formulated during previous development phases. First a clay model is created, and then reverse engineering techniques are applied to digitize its shape. Some research works have been presented in the past to optimize this phase while replacing real clay models with virtual prototypes (see Chap. 13), contributing, therefore, to sustainability. The objective has been the representation of virtual material in an immersive environment, which integrates realistic interaction for sculpting the material with virtual modeling tools similar to real ones used by designers. The interaction was realized by a specific device, which has been connected to two force feedback devices in order to let the user feel the forces arising from the virtual process [29, 30].

The conventional process has still priority in the industry. Therefore, virtual surfaces (CAD surfaces) which are used for conceptual studies are still derived from the clay model and processed by designers to obtain “class A” surfaces. Further analyses regarding ergonomics, aerodynamics, handling and production are based on these virtual surfaces to validate the car concept. The concept phase provides a product, production, sourcing, sales and marketing as well as a services concept as deliverables.

The series development phase is triggered by the end of the concept phase. Detailed design is performed and releases (for instance tooling release) are fixed as milestones. Tools, equipment as well as processes for product manufacturing are developed in this phase. Therefore, there are interactions between the product and tooling development. Components and systems are integrated into the whole car to verify that the requirements are fulfilled. For this purpose, real prototypes (pre-series and series vehicles) are built. Doing so provides a first impression of the suitability of the planned processes and prototype tools. The start of production (SOP) follows a positive evaluation of first pre-series vehicles. After that milestone, the series support strives for performing short-term optimization (e.g., quality) as well as fulfilling short-term requirements [28].

Figure 27.2 shows a representation of a simplified car modeling process, in which the stages of product development, which are to be investigated in the frame of the battery module project, are highlighted.

The battery module is an example of sustainable engineering for mobility, that will be detailed in the next chapter as case study. Similar case studies have been addressed in the past [31, 32].

Dhameja has presented an approach for simulating and validating the development of batteries for hybrid and electric vehicle applications. A performance analysis integrated with a computer-based simulation provides a baseline for the battery pack in real-world conditions. Among others, data related to power draw, engine torque, speed and acceleration of the vehicle are analyzed [31].

Peng et al. apply the concept of an open architecture product (OAP) for the development of a miniature electric car. The modification or adaptation of product modules for different requirements during the product lifecycle is the main goal of the study. The vehicle functions are mapped to design parameters using a functional structure. A common platform, functional module as well as personal feature elements are integrated through mechanical, electrical and software interfaces to realize an OAP [32]. Therefore, customers may customize their vehicle for enriching the original functions. Especially for designing electric cars, adaptability and sustainability are major factors.

However, the case study realized with EDAG Light Car is a much more comprehensive case, in which all relevant disciplines for vehicle development have been involved, applying therefore concurrent engineering on an industrial level.

Requirements for an electric car have been formulated and a development process was simulated in order to identify necessary interfaces as well as processes, tools and methods. The geometrical model of EDAG Light Car, which is a concept model of an electric vehicle, has been involved to build a proof-of-concept.

The approach that was followed throughout the elaboration of the process chain battery module is Systems Engineering. Therefore, understanding Systems Engineering basics is necessary to reconstruct the single activities which have been realized. However, a detailed excursion in that direction would exceed the scope of this chapter. A survey over Systems Engineering is presented in Chap. 9 of this book.

27.4 Process Chain Battery Module

The main objective of the project "process battery module" is contributing to sustainability through the use of an alternative, green power supply for vehicles. The first step consists of the preparation of the EDAG Light Car Model to pilot the stages of the car development process, which have been presented in Fig. 27.2. Necessary interfaces and adapters for information exchange between the disciplines involved are to be identified and processes as well as methods which enable an integrated process from the requirements definition to the stage "CAD and Simulation Body" (see Fig. 27.2) are to be defined.

In most cases, the different disciplines involved in the product development use tools that are not connected to each other. This situation is due to the fact that the different tools are proprietary and sometimes there is no standard specification that can be implemented as software interfaces or adapters to support the transmission of information from one System to another. The consequence of this fact often is the isolation of product development stages (see Fig. 27.3), which normally should be connected for tracking purposes and, therefore, managing complexity. Thus, the list of requirements commonly is not linked to functions, although functions are derived from requirements.

From an information systems (IS) point of view, this challenge may be tackled by changing the traditional application landscape of companies from a set of autonomous systems to a service-oriented architecture (SOA) [34], which enables a

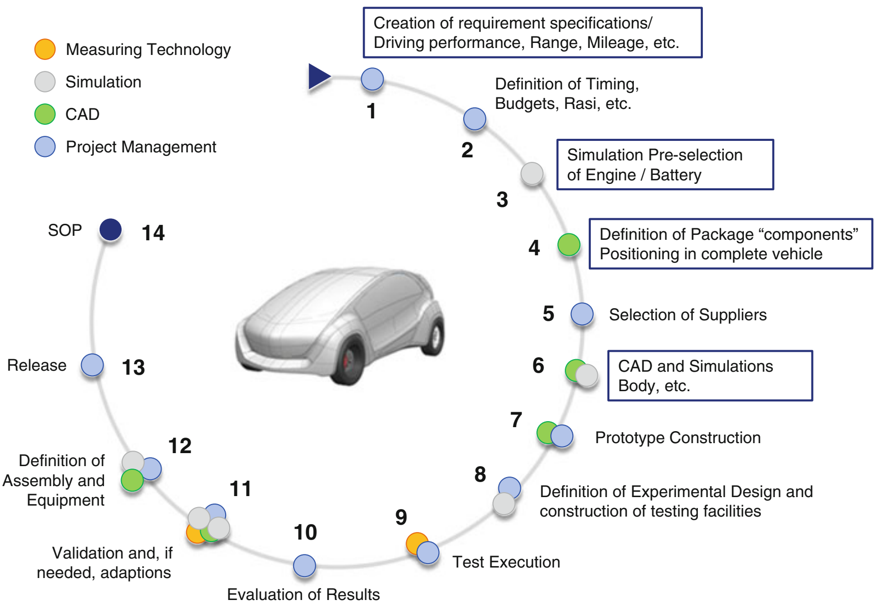


Fig. 27.2 Simplification of the car development process

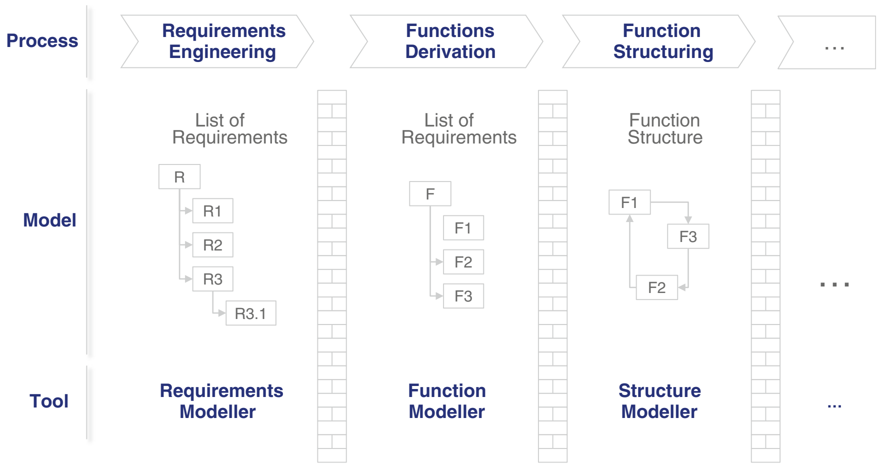


Fig. 27.3 Traditional systems engineering approach according to VDI2206 [33]

loose coupling of applications used for product development (see Chap. 4). Such a SOA can help realizing a continuous data sharing between the disciplines involved, rather than translating and importing information for each system. For this purpose, system vendors may be of importance by providing necessary interface specifications or even Application Programmable Interfaces (APIs) to enable the implementation of adapters through third parties. This objective has been emphasized by the Codex of product lifecycle management (PLM) Openness, which is an initiative of the PROSTEP iViP Association defining criteria for the openness of IT solutions used in PLM. The main target of CPO consists in bringing IT vendors to make possible the fact that data created within a company can be used throughout the entire product lifecycle (see Sect. 21.6.1) [35].

For this purpose, interoperability for an efficient collaboration, the ability to be integrated in existing IS infrastructure, functional extensibility, documented interfaces, standards as well as comprehensibility of the architecture have been adopted among others as criteria for the openness of an IT solution. The CPO-community is made up of tree types of enterprises: IT solution providers, IT integrators and customers. IT Customers can take benefit from requirements or expectations formulated withing the CPO-community to negotiate contracts with IT solution providers.

27.4.1 Methodology

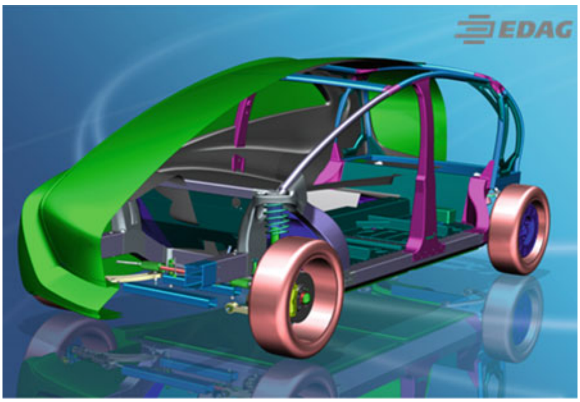
Many design methodologies have been defined in diverse VDI Guidelines (Association of German engineers), of which the VDI Guidelines 2221 and 2222 are some of the most known. VDI is the Association of German Engineers, that supports, promotes and represents them in their work. The members of VDI work on a voluntary basis in many project groups, that elaborate Guidelines for the engineering community [36]. VDI 2221 describes a general approach to develop technical systems that may be a machine, a plant, or software. The main development phases mentioned are task clarification, conceptual design, embodiment design and detail design. VDI 2222 gives a detailed explanation of methods that can be used to implement the different design phases described by VDI 2221 [37]. Pahl and Beitz describe the design process similar to VDI 2221 and provide deep details on the single steps to be followed, for instance the elaboration of a functional structure and the procedure for modeling its functions [37, 38]. The VDI 2206 provides a more suitable methodology for developing mechatronic products based on the V model [39].

For this study, a simplified methodology was followed, whereby requirements are defined and the relevant functional structure is derived accordingly [40]. The defined functions are used as input for the logical structure that represents a technological implementation of the functional structure. The next view on the product to be developed consists of the geometry representation, that is, the physical product form. The latter can be used, for instance, for performing a FEA to predict the impact of the battery (e.g., thermal influence) on surrounding parts.

27.4.1.1 Analysis Model

Input for the analysis of the process chain of the battery module has been the EDAG Light Car (Fig. 27.4), which is a vehicle concept for mobility of the near future. Some of the particularities of the EDAG Light Car are the light weight for energy efficiency, the light which is used as a central element to display functions and communication as well as the architecture in compliance with electric vehicle requirements. Furthermore, scalability has been an important requirement; therefore, the platform of the EDAG Light Car can be varied to build a car family. The integrated electric drive enables a drive-line variation for urban traffic. The battery cells are grouped into modules and positioned on the sandwich floor.

Fig. 27.4 EDAG light car



Since the development of electric vehicles differs from that of conventional cars, due for instance to the different architectures of both vehicle types, a different and appropriate way of working is required. From a tools and methods point of view, it is important to define processes and identify the tools that are suitable to tackle that challenge. Especially the influence of the battery on car behavior and structure is to be analyzed and taken into account, since it is one of the key factors of a battery-driven electrical vehicle. This calls for

- the traceability of requirements to subsystems,
- a central and whole vehicle analysis to identify the global impact of requirement parameters,
- an approach for simulation data and thermo management, which both are critical for electric vehicles,
- an intensive, distributed and multidisciplinary collaboration,
- an impact analysis of the different partial models and the management of interfaces between the different disciplines as well as subsystems in order to oversee the whole system; impacts of changes and parameters on subsystems are to be tracked and considered, and the
- transparent providence of information and technological data for process parallelization, which means that the disciplines should indicate the maturity of data in order to help other disciplines assessing the quality of data they are sharing.

The battery module is a chemical, thermal, electrical and mechanical system and is, therefore, to be developed with principles of systems engineering. The approach followed consists of defining a realistic process cycle from the definition of requirements to manufacturing. The tools and processes used for designing a conventional car were to be analyzed regarding the specificity of electrical vehicles.

For the study described in this chapter, battery cells were associated to a simplified, designed heat sink, building the so-called battery module. The modules were positioned on the floor of EDAG Light Car, allowing a rational use of space. The cell type used for this study is not typical for electric vehicles, but it often is used for applications in small serial or experimental vehicles.

One of the most important factors for performing a requirements analysis has been the ability to keep the traceability of requirements in line with the different partial models of the battery module. Doing so helps engineer efficiently assess whether some changes remain within acceptable ranges or not. Therefore, rework and loops between the disciplines involved can be reduced.

Selected requirements have been formulated for the battery module to be analyzed. Among others, the following requirements were of importance:

- Car range in km,
- Maximal velocity in km/h,
- Load time of the battery,
- Lifetime of the battery, and the
- Acceleration of the electric vehicle.

These requirements have been integrated manually into a product data management system, but it would have been possible to import them from a document or from an external requirement management tool, whereby it would have been necessary to implement an appropriate interface.

27.4.1.2 Function Structure

The main objective of building a function structure is to manage the complexity using the divide and conquer principle. Starting from the requirements, the main function as well as sub-functions can be recognized. The art consists of connecting the different identified sub-functions through logical relationships (e.g., input, output, sequence) in order to obtain the main function. Therefore, the engineer will have to look for solutions for implementing the sub-functions, which are less complex than the main function.

The function structure is solution-neutral, meaning that it defines a very high-level concept of how the main function may be realized, but it does not provide a solution like a physical component.

27.4.1.3 Behavioural Simulation

There are two main approaches for elaborating a logical model, which are signal-based modeling and object-based modeling. Signal-based modeling is characterized by explicit relationships that are defined to determine the output signal from specific input. Light modification of the physical model may lead to a major adaption of the system model. Object-oriented modeling enables inclusion of system components that are described implicitly. Virtual components correspond to real ones. For instance, there is a battery model corresponding to the real battery. Local modifications can be performed within components (e.g., battery model), which also can be replaced without modification or adaptation of the whole model. This approach is followed by the module CATIA Systems, which has been used for this study [41].

Thus, the logical structure created is represented by its logical, object-oriented components, among others the battery model and the mechanic model. These models are connected with each other using signals and dependencies (Fig. 27.5). The mechanic model is the geometrical representation of the EDAG Light Car, whereas the battery model is made out of a set of Modelica libraries developed by an external partner. Furthermore, the logical system structure is connected to requirements.

The driving cycle for the analysis is defined in Block 1. A driving cycle is a set of conditions under which a vehicle is meant to be driving to assess properties such as energy consumption or emissions. In the practice, it is a sequence of points that represent the speed of a vehicle versus the time. It is important since it helps determining the performance of different vehicles with comparable criteria. The new

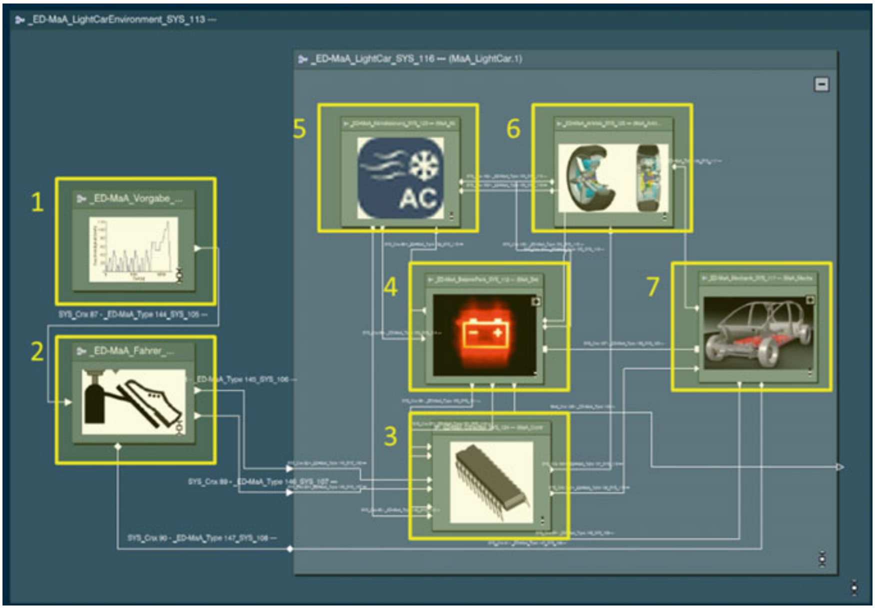


Fig. 27.5 Logical model of the whole system

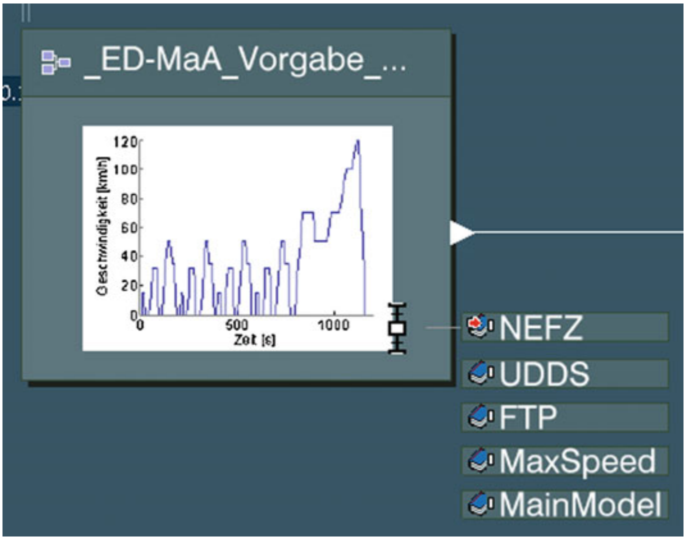


Fig. 27.6 Variation of simulation parameters

European driving cycle (NEDC), which is available on internet as value table, has been considered for this study. Other driving schedules have been considered for variation purposes (Fig. 27.6).

The driver model is represented by Block 2, which in fact is a controller that enforces the conditions prescribed by the NEDC. The controller uses the speed information of NEDC as input and triggers acceleration and braking. The controller unit of the whole system is represented in Block 3. It coordinates the different technological systems that are involved. The behavioral model of the battery module is represented by Block 4.

Since the battery has to be kept at a suitable temperature, cooling and heating are to be considered in the simulation. Block 5, therefore, represents the relevant unit.

The drive is represented by Block 6, which is an electromotor interface to the mechanical system resp. physical model through a mechanical coupling.

The chassis as well as moveable vehicle parts are building the mechanical unit, which is represented by Block 7. This unit enables taking into account dynamic driving parameters such as wind and rolling resistance.

The way of attaching models to the logical structure, for instance the mechanical model, is very important because it leads to the question, whether necessary interfaces are existing or not. Besides, this offers an opportunity to define and test standard processes. These issues are interesting from a methodological point of view.

Many simulation alternatives can be tested, whereby geometrical variations through knowledge-based engineering techniques (KBE), alternation of driving cycles as well as their values, and the change of the type of the battery cells are performed.

27.4.1.4 Selected Results

The objective of the simulation is to provide information about the performance of both battery types models (Altairnano 11 Ah, Altairnano 50 Ah) which were considered. Both battery types have been used because their modelica models already were available at one of both project partners. However, the methodology would not change if batteries of other types where to be involved in the test environment.

The results show the range of the car, the state of charge of the battery as well as the battery ageing. Furthermore, the actual speed of the simulated electric car can be compared with its nominal value. Figure 27.7 is showing such a comparison based on the NEDC.

A further point of importance in the analysis has been the thermal analysis of the cooling and heat sink. For this purpose, the thermal energy output of the battery cells has been gathered from the behavioral simulation and used as input for a transient FEA. This underlines the importance of information sharing between the different disciplines involved. Information sharing differs from information exchange in that in case of a sharing, the FEA-model can continually access necessary parameters from the battery model. When model data is just exchanged between the disciplines, mapping of both models are periodic, leading, therefore, to a lack of information on both sides and likely to data inconsistencies.

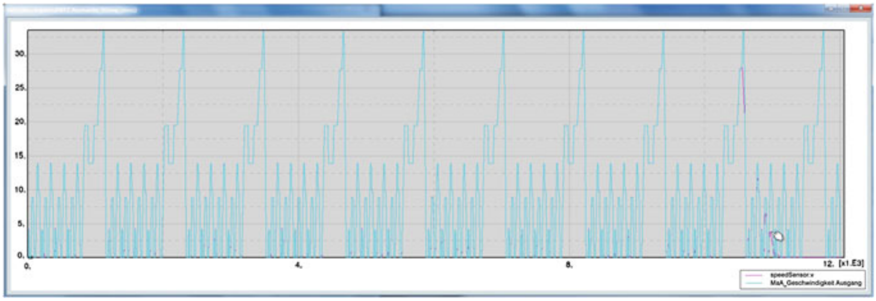


Fig. 27.7 Speed of the simulated car for a whole driving cycle according to NEDC

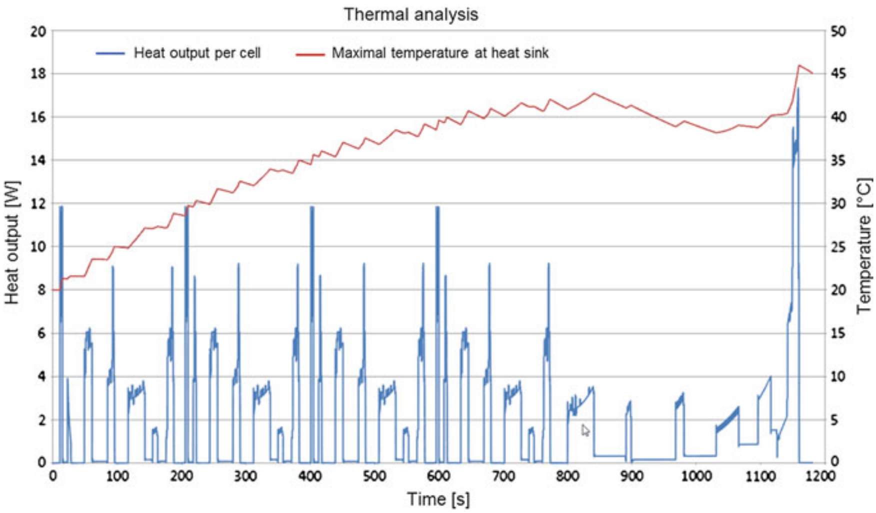


Fig. 27.8 Comparison of cell temperature with cooling temperature

Figure 27.8 shows a comparison of the cell temperature to the temperature of the cooling and heating sink. The results of the non-linear thermal analysis which has been performed are based on some assumptions made according to the project focus. For instance, the battery cells have been assembled inside a simplified, modelled battery module, that includes a simplified cooling sink. Besides the temperature distribution between the walls of the battery module have been simplified.

The case study has provided interesting information on best practices, that already is taken into account for project being implemented. The case study will be refined and enhanced in the future in order to gain more detailed information on some aspects that have been simplified, for instance the type of batteries used.

27.5 Discussion and Reflection on Concurrent Engineering

The product development following the V model (see Chap. 9), which has been partially followed for this study, provides a suitable way of working. However, applying it can be counterproductive if misused. A sequential realization of the tasks of the V model could lead to rework and, therefore, to higher costs associated with it. This could be the case if the disciplines involved work independently from each other, with the intention to merge their results at a later development stage, for instance when verifying the impact of the behavioral system on the mechanical system. For concurrent engineering to be effective, the common parameters and features that exist in the models of the different disciplines involved in product development (so-called partial models) are to be known. Relationships between these parameters are to be described in order to support a system-based model generation. Doing so would help each discipline generating its up-to-date partial model, which would have actual information from the models they are related with.

Since model or data is to be modified only by qualified personnel, the domain authority is to be respected. That is, members of each discipline should have a permission right to modify their own data (e.g., model, metadata), unless the authoring discipline explicitly has granted them modification rights.

Appropriate tools and IT services are necessary to generate domain models. Some leading solution providers have started to provide integrated environments in which different models can be mapped. However, their approach is limited to their own proprietary systems. The challenge consists of achieving a federated environment (see Chap. 4) instead of an integrated environment, in which the tools (e.g., CAD tool) and models (e.g., CAD model, behavioral model) from different vendors share data and information.

Biahmou et al. have elaborated an approach presenting the federation of the systems CATIA V5 and Matlab SimMechanics in the past [42]. In early development phases, the behavioral partial model can be derived from the geometrical one using the CAMAT (CATIA-MATLAB-Translator). A co-simulation is conducted, whereby the nominal values are sent to actuators within CATIA V5. The sensors capture values, which are sent back to the MATLAB SimMechanics model [42]. A drawback of that approach is the fact that methods must be developed to ensure the update of the different partial models involved. From this point of view, conventional autonomous tools used today and the processes based on them are not appropriate to tackle all challenges of product development. A middle way between integrated and autonomous environments is necessary (see Sect. 13.6) [43].

Based on the impact of systems engineering on all disciplines involved in product development, it might be advantageous to reorganize project teams in order to reach best performance. In fact, experience has shown that, in many companies, the requirements are shared by different disciplines, which each interpret and fulfill them, while only making little periodical adjustments together with other relevant disciplines. The overall view is, therefore, not managed since project managers not necessarily have the skills of system engineers. A promising approach consists of

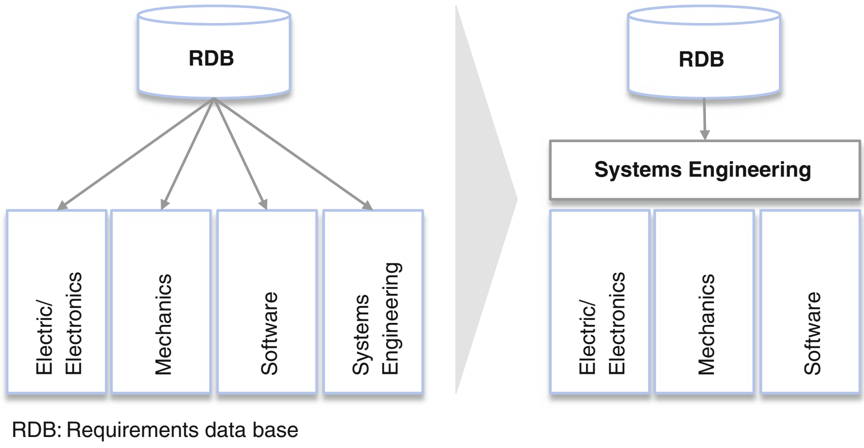


Fig. 27.9 Project organization with high performance potential

getting the requirements first in the systems engineering team, which would derive requirements for other disciplines (e.g., mechanics, electric/electronics, software), of course working in cooperation with these disciplines (see Fig. 27.9).

One of the important factors regarding the introduction of the electric vehicle is its impact on the daily life of its owner as well as on the society. Most electric vehicles have been designed with batteries to be loaded at home, even though there are some test stations for induction loading.

If the loading duration of the battery is considered, it is evident that a potential buyer would seriously ask himself what would happen the next morning, in the case he would have forget to charge the battery. This emphasizes the fact that many car makers do not seem to take seriously the fact that an electric vehicle requires new and innovative encompassing concepts rather than just introducing a battery into a car with a conventional architecture.

Electric vehicles, for instance, could be part of the power supply grid, buying and selling power according to configurations of its owner. At least, it might be interesting to equip them with the ability of automated or semi-automated triggering of the battery loading.

Besides, they could be used to stabilize the power grid which has to face instabilities due to factors such as power arising from photovoltaic solar systems or wind power plant of private persons and companies.

These instabilities nowadays already are an important challenge to be tackled by power providers. Therefore, a solution should consider the impact of some millions of batteries being charged at different times.

27.6 Conclusions and Outlook

This chapter has presented sustainable mobility as a typical field of application for Concurrent Engineering. The understanding of the term sustainability as well as its evolution in the automotive industry has been explored and actual approaches for enhancing sustainability have been presented.

First of all, the electric vehicle as an approach for alternative propulsion, but also interesting works for enhancing sustainability with alternative manufacturing processes, materials as well as drive systems have been addressed.

One important handicap of electric cars is the battery, which must power the engine. Until the customers can rely on acceptable ranges, an appropriate infrastructure and short recharging times, buying electrical vehicles certainly will remain a privilege of just a small part of the society.

Fuel cell electric vehicles are more expensive than battery electric vehicles. A fuel cell can be refilled; a battery is to be recharged. A battery stores the reluctant of its chemical reaction, fuel cell brings its reluctant to the air and, therefore, can be run as long as fuel is provided.

The focus of the work presented in this chapter has been a case study of an analysis of a battery module, a project that has been realized to contribute to sustainability through the use of an alternative, green power supply for vehicles. Since the battery design and dimensioning involves many engineering disciplines, it has been suitable for concurrent engineering application. Starting with a requirements model, a functional structure has been derived. Based on that, a logical model as well as a behavioral model have been generated. Furthermore the tools that are necessary to design and simulate an electric vehicle have been accessed during the project. It was important to emphasize the interfaces between partial models of an electric vehicle, therefore a FEA has been conducted using the physical model of the battery module.

Finally, a discussion and reflection on concurrent engineering has been made.

27.6.1 Future Perspectives

The next developments in the field of electro mobility surely will consider the question of safety when using the battery, the stability of the battery (e.g., no unintentionally battery discharge), reducing the price as well as the mass of the battery, quick loading of the batteries. Some car makers already have been facing the issue of cars burning due to battery malfunction. This calls for appropriate software, research on battery technology as well as concepts which associate power suppliers with car makers and companies, which conduct advanced research into car IT.

All these participants will have to cooperate in order to achieve synergy effects, instead of working separately, while all are pursuing the same objective. Concepts for interaction of electric vehicle and power supply infrastructures are to be developed, considering not only the battery technology, but also the availability of loading stations as well as billing concepts. Due to the fact that electric vehicles do not make the same noise as conventional cars, many people surely will not pay attention to electric vehicles driving around them. Therefore, innovative concepts for pedestrian protection will be necessary.

Stimulating the purchasing of electric vehicles remains a challenge to be tackled by politicians. It surely will be difficult to compensate the price difference between electric and conventional vehicles with only financial advantages. An additional incentive to buy electric cars may be favorable electricity prices for battery loading as well as privileges in road traffic. These may be the permission to use extra lanes, which might be otherwise reserved for special vehicles such as police cars or taxis.

Furthermore, new players could appear on the automobile market, for instance battery makers or very big IT companies such as Google, which has been conducting an important research on self-driving cars for years. This could be possible since electric vehicles do not need any combustion motor, which still represents a particular capability of today's car makers.

Sustainability will play a more important role in the future since it has become a buying criterion for cars. It is likely that potential buyers of cars will require a sustainability indicator, which takes more than the car consumption and emission into account. That indicator also would have to consider the whole lifecycle of the cars, taking the sustainability of manufacturing buildings, processes, and equipment into account [44].

Starting from the first idea of a new car to manufacturing, it will be important to assess the factors impacting sustainability in order to make an objective comparison of vehicles. New concepts of factories could be necessary to reach a high level of sustainability, for instance innovative building concepts to enable heating energy recovery.

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