INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED21
16-20 AUGUST 2021, GOTHENBURG, SWEDEN

USER NEED-ORIENTED CONCEPT DEVELOPMENT OF AUTONOMOUS VEHICLES

Schockenhoff, Ferdinand;
König, Adrian;
Zähringer, Maximilian;
Lienkamp, Markus

Institute of Automotive Technology, Technical University of Munich

ABSTRACT

Vehicle concept development is a domain that has applied and detailed its process over decades. The megatrends of the 21st century of "automation" and "sharing" influence the vehicle concept in such a manner that this well-running process needs an update. The vehicle itself and the customer of the vehicle are changing and therefore the components of the vehicle and the input variables of the user-oriented design of the vehicle concept must be changed as well. We present a development process for autonomous vehicle concepts to address these challenges. We are therefore analyzing the current definition of a vehicle concept and its development process. Based on a literature review of a selection of common design methodologies, we update this definition for autonomous vehicle concepts and present a development process that presents design concepts of autonomous vehicle in a user need oriented way. This includes the sharing of models since user needs could be fulfilled by more than one vehicle concept. We believe that the presented process can be a starting point for vehicle concept development of the 21st century.

Keywords: Autonomous vehicle concepts, Conceptual design, User centred design, New product development

Contact:
Schockenhoff, Ferdinand
Technical University of Munich
Institute of Automotive Technology
Germany
schockenhoff@ftm.mw.tum.de

Cite this article: Schockenhoff, F., König, A., Zähringer, M., Lienkamp, M. (2021) 'User Need-Oriented Concept Development of Autonomous Vehicles', in *Proceedings of the International Conference on Engineering Design (ICED21),* Gothenburg, Sweden, 16-20 August 2021. DOI:10.1017/pds.2021.596

1 INTRODUCTION

Currently, several megatrends are changing our social cohabitation. These also affect mobility and thus the automobile. In particular, the megatrends of sustainability, automation and sharing appear to have a major impact on the automobile of the future.

The megatrends of automation and sharing are strongly linked to autonomous driving and mobility-as-a-service offerings and require further research before their market introduction. Nowadays, only car show prototypes exist that have been created by industrial designers for presentation purposes. Systematic development of autonomous vehicle concepts (AVCs) under the influence of these megatrends has not yet been carried out.

With this paper, we would like to show how AVCs can be designed systematically. Therefore, we present a literature review of design methodologies and evaluate them based on identified requirements to derive a development process for AVCs.

2 STATE OF THE ART

To explain the need for redesigning the vehicle concept development process (VCDP), we want to show the traditional state of the art in the automotive industry. A definition of a conventional vehicle concept is therefore given in the following sections. Based on this definition, the corresponding automotive product development process and VCDP are explained. Additionally, we want to summarize previous research on AVCs to define the research gap for this paper.

2.1 Vehicle Concept

The most common definition of the vehicle concept is given by Braess and Seiffert (2005, p. 140). They define the vehicle concept as structural design of a product idea. This design includes the composition or compilation of the essential parameters influencing the vehicle properties and characteristics, main modules and hardware components. The vehicle concept is therefore a design with selected and positioned hardware components such as the drivetrain, chassis and body.

2.2 Automotive Product Development Process

The automotive industry has created the automotive product development process over decades. The classification of different phases and their naming vary among the automotive manufactures, but basically it can be described by the four phases of "planning phase", "definition phase", "realization phase" and "production phase" (Hahn, 2017, p. 17; Fuchs, 2014, p. 5) (Figure 1).

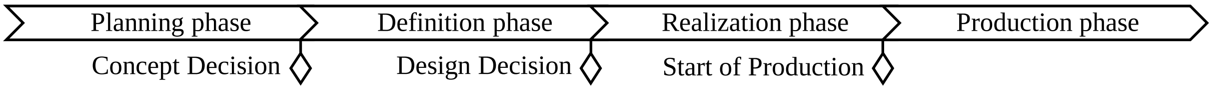

Figure 1 Automotive Product Development Process, based on (Fuchs, 2014, p. 5; Hahn, 2017, p. 17)

Over the past two decades, various improvements, e.g. concurrent engineering, have been made to these phases to achieve manufactured vehicles faster, more economically, and with greater customer focus. This is currently being continued, among other things, through research and initial implementation of IoT in the process and in manufacturing (Prasad, 2020). The focus of this paper, the concept definition, is the aim of the planning phase. Concept definition requires iteration loops for concept generation and optimization. To ensure the target orientation and the efficiency, VCDPs were established by the car manufacturers to structure this first phase of the automotive product development process.

2.3 Vehicle Concept Development Process

Researchers have dealt with the VCDP and its different aspects in various publications (Matz, 2015; Wiedemann *et al.*, 2012; Bhise, 2017; Hahn, 2017). In this paper, we are using the description of Nicoletti *et al.* (2020a), which summarizes these publications (Figure 2).

This VCDP consists of four steps. In the first step, the customer-relevant properties of the vehicle concept are determined. These customer-relevant properties are the customers' perception of the vehicle (Weber, 2007). These values such as maximum velocity must be transferred into components that can fulfill the customer-relevant properties. Component sectioning and dimensioning is therefore the second step of the VCDP. For acceleration, e.g. the motor is sized. To transition the vehicle concept in the third step, all components must be packaged. The fourth step contains the comparison of the characteristics of the vehicle concept and the initial customer-relevant property, which leads to iteration loops since some vehicle characteristics such as the vehicle weight are a consequence from the first three steps.

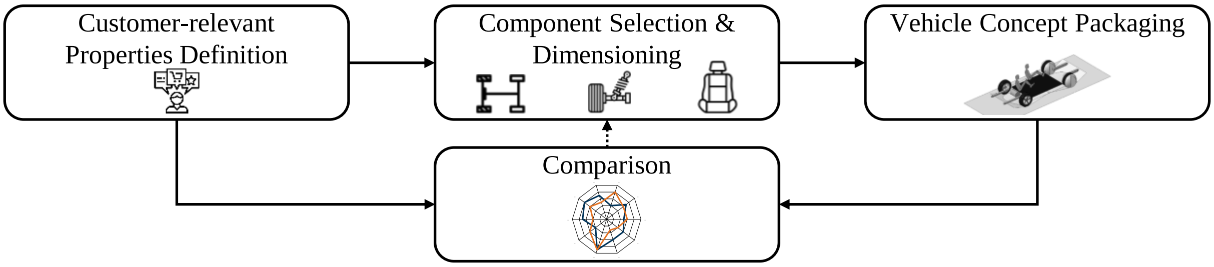

Figure 2 Vehicle Concept Development Process, based on (Nicoletti et al., 2020a)

2.4 Previous Research on Autonomous Vehicle Concepts

Current research on AVCs can be divided into two parts: First, research related to the AVCD, and second, research on specific aspects of autonomous driving. There are only a few publications on vehicle concept development (VCD), whereas there are many publications on specific aspects. The state of the art of the first group is therefore presented in a complete manner, while only examples are presented for the second group.

2.4.1 Research on Vehicle Concepts

Schockenhoff *et al.* (2020a) present a method to identify the customer-relevant properties for AVCs and a resulting portfolio. They classify them into the three categories of similar properties, changed properties and new properties compared to the portfolio of conventional vehicle concepts, which is given by (Rudolph *et al.*, 2011; Wiedemann *et al.*, 2012; Ziemann, 2007). The new whole vehicle properties they identify are Boarding, Quality of Secondary Activity, Updatability and Environmental Communication.

Koenig *et al.* (2019) show the influence of auxiliary consumers on the AVC. Some components and modified use cases increase the total energy demand of the vehicle, to which the AVC must be adapted. For example, autonomous driving with sensors and increased computing power requires additional energy. In addition, auxiliary consumption increases with use cases such as ridesharing, since air conditioning becomes more energy intensive owing to the higher number of door openings.

Sethuraman *et al.* (2020) and Pathak *et al.* (2020) focus on the VCD of autonomous buses in Singapore. They developed a method for the design of autonomous bus concepts that includes the requirements of a mega city. Accordingly, costs, emissions and availability of the buses are key aspects. They present a tool to automatically generate package models of autonomous buses for the given requirements.

2.4.2 Research on Specific Aspects of Autonomous Driving

There are various publications discussing specific aspects of autonomous driving such as driving comfort, driving algorithm and the human machine interface (HMI). The following three examples demonstrate how detailed research on subfunctions of an AVC can influence the VCD.

Schockenhoff *et al.* (2020b) deal with a new aspect of AVCs. Driving style is an important aspect to fulfill user needs in autonomous driven vehicles. They therefore defined driving style as a four-dimensional value compromising driving comfort, travel time, safety, and economic efficiency. In their publication, they present a methodology to address the interdependencies of these dimensions in driving maneuvers to evaluate the driven driving styles. Since driving style will be an important customer-relevant property of an AVC, the dimensions of the driving style must be considered in the property portfolio and the methods to test them should be part of the vehicle concept evaluation.

Koch *et al.* (2020) present an eco-driving algorithm to deal with the interdependence of the drivetrain and the driven driving style. They show the energy saving potentials and the downsizing potentials due to a co-optimization of multiple motors and gears. Their publication illustrates the room for improvement in the AVCD by considering the interdependencies of hardware and software components of the vehicle modules such as the drivetrain. This interaction of hardware and software must be considered in the AVCD.

Fank *et al.* (2019) address the HMI in semi-automated vehicles. These deal with the anthropomorphism of these systems. In a first step, (Fank *et al.*) present an overview of existing HMI systems in current vehicles and how these increasingly include features of anthropomorphism. In a second step, (Fank *et al.*) introduce two possible systems for trucks. Although the publication only focuses on conditional automated vehicles and trucks, the need to include the HMI in the AVCD is evident.

2.5 Research Gap

In summary, research on AVCs is an upcoming topic. Publications on AVCD already exist, but they either only address one mobility solution or cover only smaller elements of a holistic process. There are research findings on specific aspects of autonomous driving that need to be considered in the AVCD.

Since the vehicle concept definition of Braess and Seiffert (2005, p. 140) does not consider the mentioned megatrends of automation and sharing that will influence future vehicles, a new definition of an AVC is required to specify the aim of the VCDP. Thus, based on section 0. we want to provide the following new definition for AVCs:

The concept of autonomous vehicles is the structural design of a product idea. In the future, this design will include not only the hardware components, such as the drivetrain, the sensor set, the body, interior design and the resulting main dimensions, but also software modules that describe initial requirements and characteristics in the areas of driving functions and comfort functions. Functional characteristics that describe the user experience in terms of entertainment are attributed to the fleet operating concept.

With this definition of AVCs and the development of user-oriented vehicle concepts for different future mobility solutions, the following research question arises:

How must the conventional vehicle concept development process be enhanced to develop autonomous vehicle concepts in a user-oriented way?

Since the whole process requires the elaboration of the individual process modules, they should be run through automatically to deliver quick results and the results should be quantitative to enable comparability. The following second research question is based on the first one:

What should the implementation of the individual process modules look like to be able to automatically generate quantitative assessments of AVCs?

3 DESIGN METHODOLOGIES

To answer the first research question, a closer look at different design methodologies is required. The most suitable theory for the stated question could be the basis to create the AVCD process.

Several design methodologies exist. We want to focus on the selection of the six methodologies Design for X (e.g. Six Sigma), Munich Procedure Model, Axiomatic Design, V-model, Design Thinking and Characteristics-Properties Modeling since these are common methods and have meaningful approaches in regard to our research question.

3.1 Design for X (e.g. Six Sigma)

Design for X is a design approach to develop a product for a specific purpose. In this paper, Design for Six Sigma (Figure 3) is chosen as example of Design for X. Design for Six Sigma was established in the 1980s by Motorola (Smith, 2003). It is a design method to improve the quality of the product. The five-step process “Define” - “Measure” - “Analyze” - “Design” - “Verify” was therefore developed (Breyfogle, 2003, pp. 124–167).

In the “Define” stage, the issue must be specified. During the “Measure” step, all information about the issue should be collected. The third stage analyses potential solutions which are implemented in the “Design” stage. The final step “Verify” reviews the product to check the disposal of the issue.

Figure 3: Design for Six Sigma, based on (Breyfogle, 2003, pp. 124–167)

3.2 Munich Procedure Model

The Munich procedure model (Figure 4) according to Lindemann (2009, pp. 46–54) consists of seven blocks that are based on the three main steps of “Clarify target/problem”, “Generate solution alternatives” and “Make decisions”. It represents a procedure model that combines the advantages of other procedure models. In particular, the abandonment from sequential procedures and allowance of iterations is promoted by the fact that no path is specified in the model. It is therefore flexible and can be adapted to the respective situation by the client without strict guidelines.

Figure 4 Munich Procedure Model, based on (Lindemann, 2009, p. 47)

3.3 Axiomatic Design

Suh *et al.* (1978) developed the Axiomatic Design method (Figure 5) in 1978. The four-step process leads from the question “What adds value?” to the question “How it is made?”. In the first domain, which the steps of Axiomatic Design are called, customer needs for the desired product are collected. The second domain translates them into solution-neutral technically described functional requirements. In the third domain, the physical design parameter that fulfill the functional requirements are selected and dimensioned. The last domain defines the production process of the product. (Suh, 2001)

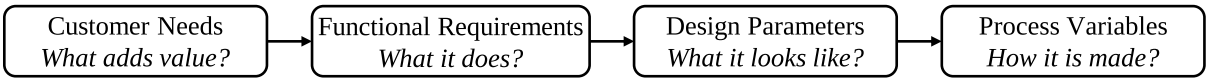

Figure 5: Axiomatic Design, based on (Suh, 2001)

3.4 V-model

The V-model (Figure 6) invented by Boehm (1979) and standardized in VDI 2206 (VDI, 2004) is a common process to develop mechatronic systems. The product is specified on the left wing, and it is tested on the right wing. At the bottom of the V, the product is implemented. The specification of the product proceeds from the overall system to individual subsystems, while the testing starts with the individual subsystems and ends with the overall system.

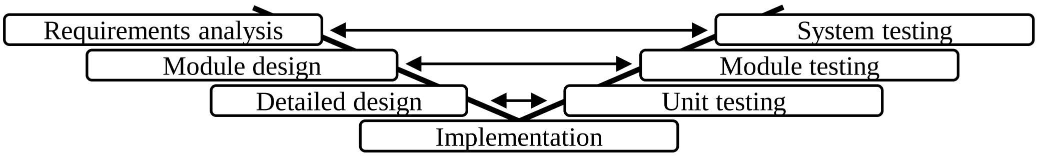

Figure 6: V-model, based on (VDI, 2004)

3.5 Design Thinking

Design Thinking (Figure 7) is a method that supports interdisciplinary creativity to develop products that are oriented on user needs. The idea is to create iteratively improved prototypes as quickly as possible and to test them in terms of meeting user needs. Therefore, the steps are empathize (with the users), define (the problem), ideate (solutions), prototype (the product) and test (Plattner *et al.*, 2011).

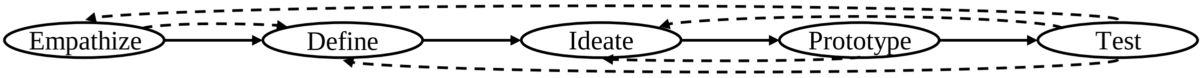

Figure 7: Design Thinking, based on (Plattner et al., 2011)

3.6 Property-Driven Development/Design

The Property-Driven Development/Design of Weber (2007) (Figure 8) is based on the differentiation between the properties and characteristics of a product. The properties are the “product's behavior”, which is the customer's view on the product and the characteristics are defined as the “structure and shape of the product”, which is the engineer's point of view. To create products (synthesis) and to test products (analysis), it is important to define relations between the properties, the and the dependencies between the characteristics. Based on this modeling, products can be designed and tested.

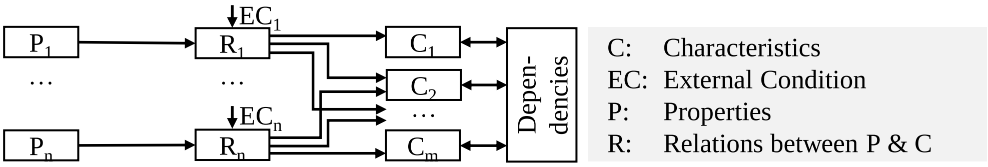

Figure 8: Property-Driven Development/Design, based on (Weber, 2007)

3.7 Assessment of the Design Methodologies

To identify the methodologies which are possible backbones of the AVCD process, we compare the presented methodologies with requirements that are derived from the research questions in Table 1.
Regarding this comparison, the framework of Axiomatic Design with the first three domains of user needs, functional requirements and design parameter fits best with the AVCD. Thus, the idea of Axiomatic Design is used for the process which we present in section 4.

Table 1 Comparison of the Design Methodologies

	Conv. VCD compatible	Customer-/ user-oriented	Hardware & Software	Automated process	Quantitative results
Design for X (e.g. Six Sigma)	◔	◑	◕	◔	◕
Munich Procedure Model	◑	◕	◑	○	◑
Axiomatic Design	◕	●	◕	◕	●
V- model	◕	◑	●	◑	●
Design Thinking	◔	●	●	○	◑
Property-Driven Development/Design	◑	●	◑	◕	◕

● completely suitable ◑ partly suitable ○ completely unsuitable

4 DEVELOPMENT OF AUTONOMOUS VEHICLE CONCEPTS

To present the designed framework for the AVCD, we first introduce our holistic process and detail its steps.

4.1 Holistic Process

As described, a modified version of Axiomatic Design builds the backbone of our framework (Figure 9). The wording is adapted to the common one in the automotive sector and new steps are added to consider the mentioned megatrends. The three steps of customer-relevant properties, technical properties as well as component selection and dimensioning are like the domains of Axiomatic Design.
Since the customer-relevant properties are related to one vehicle, but owing to the megatrend of sharing one private AVC will not only cover the mobility needs of one person; the user-bound mobility needs are queried as input of the holistic process in a preceding process step. These user-bound mobility needs include mobility behavior, desired secondary activities during the ride and character traits related to mobility. The customer-relevant properties define the input for one AVC and maintain their role in the conventional VCDP. Only the portfolio will change, as mentioned in section 2.4. In summary, the term user refers to all the mobility needs of a person, while a customer relates to

the vehicle whose passenger he or she is at that time or for that purpose. The technical properties are derived from the customer-relevant properties and enable the selection and dimensioning of hardware and software components. The AVC is designed by merging the hardware components into a package plan and the software components into the software architecture. Since input of the process is a mobility need, the output is a fleet of several AVCs to fulfill the mobility needs.

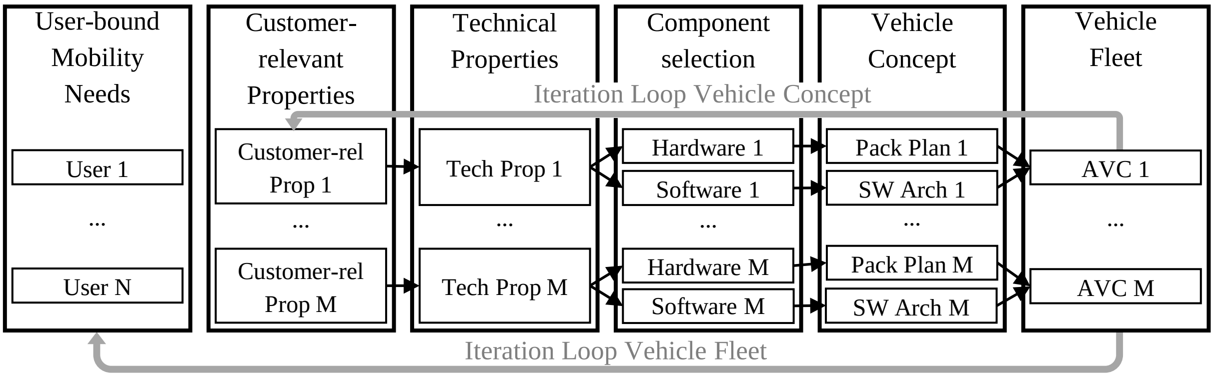

Figure 9: Development Process of AVC

In the first step, N users declare their mobility needs. Each user is assigned a vector of his individual needs. Since it is not possible to design a separate vehicle for each individual need of each user, M AVCs are created, which are described by their customer-relevant properties. Thereby, M is smaller than the sum of all individual needs resulting from N. From this process step onwards, each AVC can be considered independently. From the customer-relevant properties of an AVC, the technical properties are created. They are a technical and solution-neutral description of the AVC and define the input for the component selection. To be able to develop AVCs defined in section 2.5, the software components must be selected and dimensioned or specified in addition to the hardware components. Up to this process step, the hardware and software components are not one quantity but the vector of all individual components. To combine them, they are merged in the Vehicle Concept process step. For the hardware, this is realized with a package plan and with the software via the software architecture. Finally, the package plan and the software architecture define the AVC. The iteration loop of the conventional VCD (section 2.3) can be performed for each individually generated AVC. By merging the AVCs, a vehicle fleet is created to fulfill the initially defined user-bound mobility needs in an optimized way. This vehicle fleet consists of the different AVCs but does not contain information about the required numbers of each AVC. Therefore, a second iteration loop helps to compare the designed vehicle fleet with the desired user needs. The following sections will deal with the description of the process steps in more detail.

4.2 User Needs to Customer-relevant Properties

The derivation from customer-relevant properties of user-bound mobility needs has two aspects (Figure 10). Firstly, the mentioned minimization of the number of required vehicles to satisfy user needs, and secondly, the conversion of these needs into vehicle-related customer-relevant properties. Thus, we propose a separation of these two tasks and implementation of the intermediate step called vehicle-bound mobility provision, which presents the minimalized number of AVCs. In this case, the first step is an optimization with the objective of a minimum number of AVCs at a given user fulfillment level which denotes the desired satisfaction of users' needs. The second step must transform the vehicle-bound mobility provision into customer-relevant properties. Both exist in a qualitative, partly not directly measurable format. Hence, a multicriteria decision making method is required.

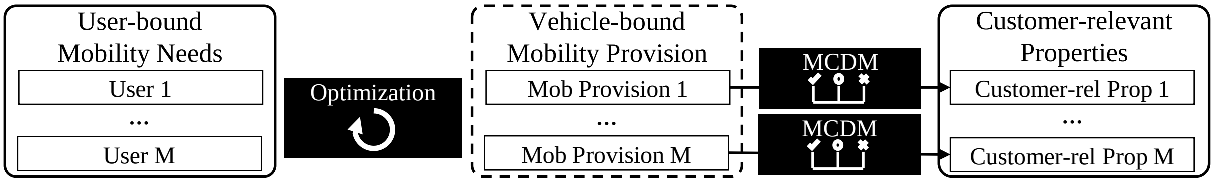

Figure 10: Development of Customer-relevant properties from User-bound Mobility Needs

4.3 Customer-relevant Properties to Technical Properties

To get technical properties from customer-relevant properties, correlation functions are suggested in the literature (Wiedemann *et al.*, 2012; Deubel, 2007, p. 52). Thereby, the qualitative customer-relevant property could be converted into quantitative technical properties. If a customer-relevant property needs more than one technical property to get fulfilled, this can be achieved by weighting the technical properties. The two possible correlation functions could be an accumulated Gaussian distribution in a positive or a negative correlation. A positive correlation describes a distribution in which a higher value of the customer-relevant property requires a higher value of the technical property. A negative correlation requires a lower value of the technical property (Deubel, 2007, p. 52).

4.4 Technical Properties to Component Selection and Dimensioning

The selection and dimensioning of components is responsible for the fulfillment of technical properties. Components can be hardware parts on the one hand and software functions on the other hand. One or more of them are linked to a technical property. Linking components with a technical property is complex and often cannot be achieved by means of a correlation. Instead, simulations are used that model the behavior of components. Whenever possible, we use existing simulations or we develop new simulation tools like a longitudinal dynamic simulation (König *et al.*, 2020).

Today's simulations are mostly aimed at the design of the hardware. Since the interdependencies of software and hardware described in section 2.4.2 have to be considered, a new modelling of these simulations is necessary. However, for a first rough assessment, a factor that emulates the contribution of a software component to the fulfillment of a specific technical property could be integrated into today's simulation models and thus provide a first approximation for the design of the components of AVC.

4.5 Component Selection and Dimensioning to Vehicle Concept

After the selection and dimensioning of every component, they have to be combined into a vehicle concept. The interaction between components can take place on different levels. Hardware components interact with other hardware components, and thus changes in weight of one hardware component can on the one hand cause secondary changes in the weight of other hardware components. But since weight is often linked to the volume via the density, weight changes can also cause changes in volume and thus in the dimensions of the complete vehicle (Nicoletti *et al.*, 2020b).

In addition, software components interact with hardware components since e.g. they require computing power on computers and software components interact with other software components for this computing power.

We are therefore using simulation models that include all the component models above. Since a lot of interactions between components and the AVC result in high complexity of the system, we use optimization algorithms to find optimal solutions.

4.6 Exemplary Use Case

The following use case is not a result of a simulation. It should only illustrate how our framework works: A family of four has different mobility needs. Father, mother and the two children want to work, relax or sleep in the vehicle. They also differ significantly in their willingness to use mobility-as-a-service solutions and their willingness to invest. The provided vehicles should therefore vary in the possible secondary activities and the fulfillment of the personal characters. The optimization in the first step could lead to 5 vehicles for the family.

One of these is a taxi, especially designed for the secondary activity sleeping. Accordingly, this vehicle concept has in the customer-relevant properties a comfortable driving style, a very comfortable vertical dynamics, a very high seating comfort etc. Those are converted for the technical properties into values for maximal jerk of the driving style, maximal body accelerations and maximal backrest angle. The hardware components wheel suspension and seat as well as the software components driving style can be designed using these values, among other values. A package plan is created by combining all hardware components. The package plan and the software components merged in the software architecture result in the vehicle concept, that is designed for the secondary activity of sleeping. It may be rather long, wide and flat in its outer dimensions and may offer less entertainment than a vehicle concept for relaxing. With the process being completed for the other 4 vehicles, the fleet that covers the mobility needs of this family would be created.

This short example shows how our presented framework to develop AVC works. An automotive manufacture, that want to build these vehicle concepts, or a car sharing company, that want to buy them to provide mobility solutions, would run this process with the needs of all their possible customers to develop the whole fleet they want to sell or buy.

5 DISCUSSION AND OUTLOOK

We believe that ours is the first publication focusing on the systematic design of AVCs. Our presented AVCD process is still close enough to the conventional one to be able to continue using proven methods and not to have to start from scratch. The development of a single AVC is similar in hardware design to a conventional vehicle concept, whereas software influences on the hardware and other new conditions, such as the elimination of the driver's workplace, must be considered. Accordingly, the focus on user needs and the corresponding process steps is completely new and the design of the further steps has changed significantly.

It is possible that potentials that arise in the development of cyber-physical systems are not addressed by using parts of the conventional VCDP. But in the development of a novel AVC, the integration of existing processes seems reasonable. Nevertheless, we believe that our approach enables the AVCD without comparable predecessor vehicles and thus initiates research on the AVCD process.

In conclusion, we present a definition of an AVC and we derive a methodology to develop them systematically. We use the conventional VCDP as a basis and modify it to consider the megatrends of automation and sharing of the 21st century. For this purpose, we compared existing design methodologies. Based on this comparison, we selected Axiomatic Design as the backbone of our method, which consists of the six main steps of “user-bound Mobility Needs”, “Customer-relevant Properties”, “Technical Properties”, “Component Selection”, “Vehicle Concept” and “Fleet Concept”.

The exemplary use case we have used to illustrate the process is not sufficient to validate its functionality. This paper only presents its theoretical derivation, which is essential for a systematic approach to the development of novel product concepts such as AVCs.

Therefore, our future research will address the detailing and implementation of every step of this process. We want to make concrete suggestions for the implementation of the individual process steps in addition to this holistic process. With this fully simulated process, we can prove its functionality and confirm the described strengths in the development of AVCs. Finally, we will develop AVCs based on the presented process.

In a later industrial applications, this will enable automotive manufacturers to address the challenges of the 21st century described above and plan their future vehicle fleets in a user need oriented manner.

CONTRIBUTIONS

F.S. initiated this paper and developed the concept. He conducted the research on AVCD. He also initiated all steps of the methodology. He wrote 95 % of the paper. A.K. worked on the last steps of the process and wrote 5 % of the paper. M.Z. developed the first steps of the process with F.S. and reviewed the holistic process. M.L. made an essential contribution to the concept of the research. He critically revised the paper for important intellectual content. M.L. gave final approval of the version to be published and agrees to all aspects of the work. As a guarantor, he accepts responsibility for the overall integrity of the paper. Student Maximilian Ernster gave his support in the literature review. Many thanks to Clemens Pizzinini and Philipp Hafemann for inspiring feedback.

ACKNOWLEDGMENTS

This research is accomplished within the project “UNICARagil” (FKZ 16EMO0288). We acknowledge the financial support for the project by the Federal Ministry of Education and Research of Germany (BMBF).

REFERENCES

Bhise, V.D. (2017), *Automotive product development: A systems engineering implementation*, CRC PressTaylor & Francis Group, Boca Raton, London, New York.

Boehm, B.W. (1979), “Guidelines for Verifying and Validating Software Requirements and Design Specifications”, in Samet, P.A. (Ed.), *Euro IFIP 79*, North Holland, pp. 711–719.

Braess, H.-H. and Seiffert, U. (Eds.) (2005), *Handbook of automotive engineering, SAE-R*, Vol. 312, SAE Internat, Warrendale, Pa.

Breyfogle, F.W. (2003), *Implementing six sigma: Smarter solutions using statistical methods*, 2nd ed., Wiley, Hoboken, NJ.

Deubel, T. (2007), “Anforderungs-, kosten- und wertgetriebene Steuerung des Produktentwicklungsprozesses”, Dissertation, Institute of Engineering Design, Saarland University, Saarbrücken, 2007.

Fank, J., Richardson, N.T. and Diermeyer, F. (2019), “Anthropomorphising driver-truck interaction: a study on the current state of research and the introduction of two innovative concepts”, *Journal on Multimodal User Interfaces*, Vol. 13 No. 2, pp. 99–117.

Fuchs, J. (2014), *Analyse der Wechselwirkungen und Entwicklungspotentiale in der Auslegung elektrifizierter Fahrzeugkonzepte, Audi Dissertationsreihe*, v.99, 1st ed., Cuvillier Verlag, Göttingen.

Hahn, J. (2017), *Eigenschaftsbasierte Fahrzeugkonzeption*, Dissertation, *AutoUni - Schriftenreihe*, Vol. 108, Springer Fachmedien Wiesbaden, Wiesbaden.

Koch, A., Bürchner, T., Herrmann, T. and Lienkamp, M. (2020), “Eco-Driving for different Electric Powertrain Topologies considering Motor Efficiency”, *World Electric Vehicle Journal*, submitted.

Koenig, A., Schockenhoff, F., Koch, A. and Lienkamp, M. (2019), “Concept Design Optimization of Autonomous and Electric Vehicles”, in 2019 *8th International Conference on Power Science and Engineering (ICPSE), 2019, Dublin, Ireland*, IEEE, pp. 44–49.

König, A., Nicoletti, L., Kalt, S., Moller, K., Koch, A. and Lienkamp, M. (2020), “An Open-Source Modular Quasi-Static Longitudinal Simulation for Full Electric Vehicles”, in 2020 *Fifteenth International Conference on Ecological Vehicles and Renewable Energies (EVER)*.

Lindemann, U. (2009), *Methodische Entwicklung technischer Produkte: Methoden flexibel und situationsgerecht anwenden*, 3., corr. Ed., Springer, Berlin.

Matz, S. (2015), “Nutzerorientierte Fahrzeugkonzeptoptimierung in einer multimodalen Verkehrsumgebung”, Dissertation, Institute of Automotive Technology, Technical University of Munich, Munich, 2015.

Nicoletti, L., Brönner, M., Danquah, B., Koch, A., König, A., Krapf, S., Pathak, A., Schockenhoff, F., Sethuraman, G., Wolff, Sebastian and Lienkamp, M. (2020a), “Review of Trends and Potentials in the Vehicle Concept Development Process”, 2020 *Fifteenth International Conference on Ecological Vehicles and Renewable Energies (EVER)*.

Nicoletti, L., Romano, A., König, A., Schockenhoff, F. and Lienkamp, M. (2020b), “Parametric Modeling of Mass and Volume Effects for Battery Electric Vehicles, with Focus on the Wheel Components”, *World Electric Vehicle Journal*, Vol. 11 No. 4, p. 63.

Pathak, A., Sethuraman, G., Ongel, A. and Lienkamp, M. (2020), “Impacts of electrification & automation of public bus transportation on sustainability—A case study in Singapore”, *Forschung im Ingenieurwesen*.

Plattner, H., Meinel, C. and Weinberg, U. (2011), *Design Thinking*, mi-Wirtschaftsbuch, Munich.

Prasad, B. (2020), “Product development process for IoT-ready products”, *Concurrent Engineering*, Vol. 28 No. 2, pp. 87–88.

Rudolph, H.-J., Soppa, T., Dahlems, C. and Meurle, J. (2011), “Der neue Audi Q3 - Fahrzeugkonzept”, *ATZextra*, Vol. 16 No. 7, pp. 18–23.

Schockenhoff, F., König, A., Koch, A. and Lienkamp, M. (2020a), “Customer-Relevant Properties of Autonomous Vehicle Concepts”, *Procedia CIRP*, Vol. 91, pp. 55–60.

Schockenhoff, F., Nehse, H. and Lienkamp, M. (2020b), “Maneuver-Based Objectification of User Comfort Affecting Aspects of Driving Style of Autonomous Vehicle Concepts”, *Applied Sciences*, Vol. 10 No. 11, p. 3946.

Sethuraman, G., Schwarz, M., Maxl, S., Ongel, A., Lienkamp, M., Ng, H.W. and Raksincharoensak, P. (2020), “Development of an Overall Vehicle Sizing and Packaging Tool for Autonomous Electric Buses in the Early Concept Phase”, *SAE International Journal of Commercial Vehicles*, Vol. 13 No. 1.

Smith, B. (2003), “Lean and Six Sigma - A one-Two Punch”, *QUALITY PROGRESS*, Vol. 36 No. 4, pp. 37–41.

Suh, N.P. (2001), *Axiomatic design: Advances and applications, The MIT-Pappalardo series in mechanical engineering*, Oxford Univ. Press, New York, NY.

Suh, N.P., Bell, A.C. and Gossard, D.C. (1978), “On an Axiomatic Approach to Manufacturing and Manufacturing Systems”, *Journal of Engineering for Industry*, Vol. 100 No. 2, pp. 127–130.

VDI (2004), *Design methodology for mechatronic systems* No. VDI 2206.

Weber, C. (2007), “Looking at “DFX” and “Product Maturity” from the Perspective of a New Approach of Modelling Product and Product Development Processes”, in Krause, F.-L. (Ed.), *The future of product development: Proceedings of the 17th CIRP Design Conference*, Springer, Berlin, New York, pp. 85–104.

Wiedemann, E., Meurle, J. and Lienkamp, M. (2012), “Optimization of Electric Vehicle Concepts Based on Customer-Relevant Characteristics”, *SAE 2012 World Congress and Exhibition*.

Ziemann, A. (2007), *Zielsystemmanagement für die Produktentstehung von PKW*, Books on demand, Norderstedt.