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Andreas Wagner *Hrsg.*

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E/E-Architecture

Mercedes “S-Class” Powernet Architecture

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Abstract. The brand-new S-Class is the beacon of automotive luxury, which addresses evolving customer expectations and technical opportunities. We enter into a new era in the automotive Powernet domain. Optimization in both power availability and drive hybridization, as well as new features such as partial networking characterize the highly integrated state-of-the-art Mercedes powernet. The new S-Class offers heightened energy efficiency and increased reliability for further automation of driving and vehicle features. The systematically optimized E/E network architecture for the 2020 S-Class maximizes the availability of automotive electronics innovations. Mercedes-Benz further enhances the energy-efficient and cost-effective power supply with the improved 48V system. It prepares for the latest driver assistance and automation systems with a fail-safe 12V power supply. Furthermore, a new vehicle feature experience is defined before and after driving with a “Living” powernet. Since the initial launch in the 222 predecessor, the fully integrated 12V and 48V power network system increases the energy availability for additional comfort and chassis innovations with consumption-reducing EQ hybrid features culminating in the realization of the 223 model.

Keywords: Powernet integration · Energy efficiency · Powerpack · Feature availability · “LIVING” powernet · User centric · Vehicle states · Partial networking

1 Electrical Signature

Automobile innovations are ever-increasingly dependent on electric power. The systematically optimized new S-Class powernet architecture (Fig. 1) provides for maximum availability of all electronically controlled features to our customers. Mercedes-Benz is rolling out a new dimension of “Living” powernet with the further enhanced 48V system, a supplementary 12V system for the latest driving assistance systems and a unique degree of systems integration enabling more powerful, more reliable and at the same time more efficient electric supply.

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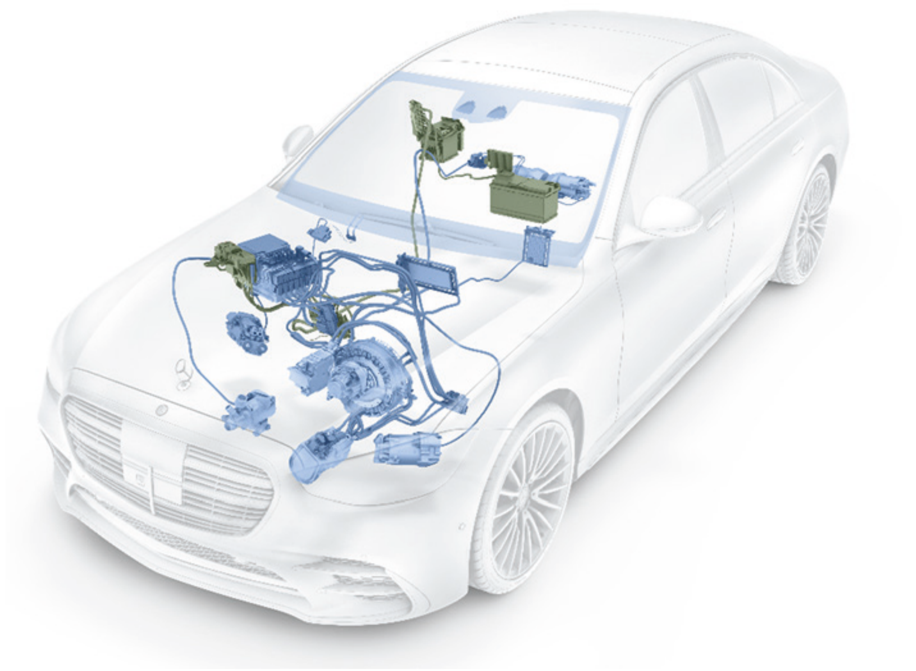

Fig. 1. Frontal view of Mercedes-Benz S-Class powernet component

2 Energy-Efficient Powernet System with 48V

The next stage of evolution of the 48V on-board electrical system made-by-Mercedes launched in the new S-Class. The complete integration of the 12V and 48V powernet systems already extended the electrical power supply for the most modern comfort and suspension systems with the consumption-reducing EQ hybrid functions in the predecessor model. As a technological leader, Mercedes-Benz consistently expands its approach in connection with the introduction of the latest generation of its E/E architecture (STAR3). The fully integrated two-voltage powernet systems of the new S-Class consists of the classic 12V and the 48-V on-board electrical system, Fig. 2.

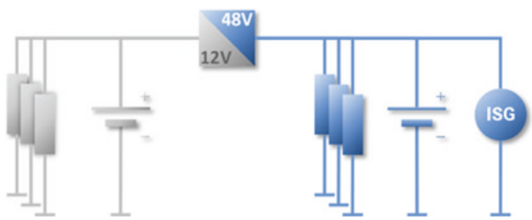

Fig. 2. Basic 12V/48V powernet architecture

A drivetrain-integrated starter generator (ISG) replaces the previous 12V alternator and the pinion starter completely. By placing the integrated starter generator on the 48-V side, where it can provide four times more power than the previous 12V alternator, we exploit the full system potential. An efficient DC/DC converter maintains the supply of the 12V on-board electrical system. Both on-board electrical systems feature a battery, ensuring availability of electrical energy, particularly when the combustion engine is off. To meet the performance and charging requirements the 48V battery relies on lithium-ion cells. Since the 48-V integrated starter generator starts the combustion engine from the 48V power battery, the size of the 12V lead battery could be reduced, whilst increasing the energy reserve of the overall vehicle through optimized deep discharge protection. Previously available and new innovative high-performance consumers of both, the driving and the comfort domains, now rely on the 48V power supply. Both measures increase the efficiency of the energy supply and reduce the vehicle weight.

3 48V Powerpack Integrates 12V/48V Vehicle Powernet

The centerpiece of the on-board electrical systems’ integration is the 48V Powerpack from Mercedes-Benz – see Fig. 3. The Powerpack has the size of a conventional 12V battery, weighs around 5kg less and was further optimized after its initial launch with the predecessor model in September 2017. The lower part of the Powerpack is the 48V battery. It consists of twelve lithium-ion cells connected in series with a peak output of 16kW and has a capacity of 20 Ah. The battery’s control electronics hosts the battery management system (BMS). The top of the Powerpack integrates the bidirectional DC/DC converter to enable variable coupling of the 12V and 48V side. The DC/DC converter can supply either the 12V on-board electrical system with 3kW continuous output or charge with up to 1kW from the 12V powernet into the 48V on-board electrical system. It not only electrically links the 48V powernet system with the 12V side but also contains the control interface between the energy management of the powertrain, the on-board electrical system management of the overall vehicle and the large, powerful 48V battery. In addition, a cooling plate with water connection and a thermally fast Peltier element were integrated. When the battery is cold, the Peltier element acts as a battery heater with improved cooling performance for heated batteries and thus guarantees a maximum of energy-efficient 48V powernet system performance even at extreme temperatures.

Fig. 3. The 48V powerpack at the heart of powernet systems integration

Additional components were added to the 48V on-board electrical system compared to the predecessor – compare Fig. 4. For example, the optional 48V chassis E-ACTIVE BODY CONTROL (eABC) is new in the S-Class. With the previous 12V technology, such an electrically active performance suspension was not feasible due to power and high currents required. It is important for Mercedes-Benz to implement energy efficiency in safety and comfort features such as the eABC in the S-Class. This was achieved with the 48V chassis, which only consumes valuable electrical energy during active dynamic interventions to reduce the nodding, rolling and tilting of the chassis to a comfort level typical for an S-Class. During active electrical compensation of vehicle body movements the eABC acts like a generator as it recuperates power back to the 48V Powerpack. Thus, energy recuperation was not only implemented in the drivetrain, but in the chassis, too. Two new, fast and powerful electric 48V auxiliary heaters boost climate comfort in the vehicle interior in cold outside temperatures. The transition of the auxiliary heaters from 12V to 48V not only offers more comfort, but also reduces energy transmission losses at identical power levels due to smaller currents and, whenever possible, feeds from previously recuperated 48V battery charges.

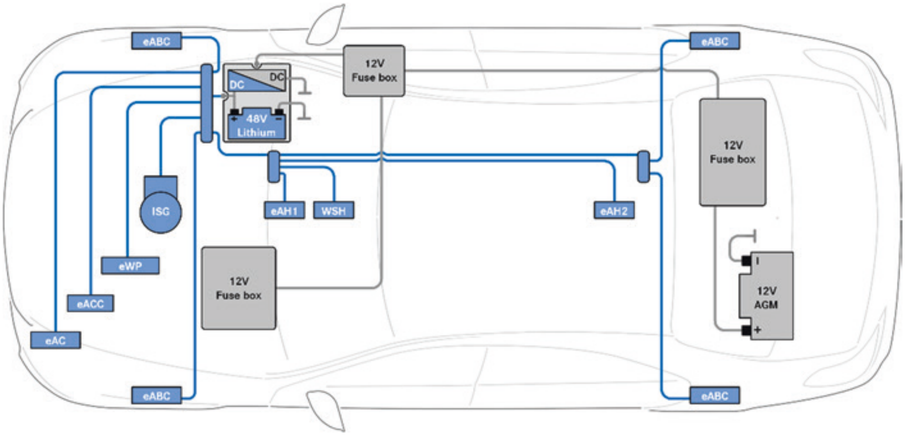

Fig. 4. 12V and 48V powernet vehicle integration

The increased number of 48V components makes the new S-Class electrically unique, Fig. 4. The full integration of the 12V powernet with the 48-V on-board electrical system enables unprecedented comfort, impressive performance and a heightened degree of safety with reduced consumption, which cannot be achieved with the common 12V-only power network due to limitations of battery size and generator.

4 Feature Availibility

On its clear strategic path to automated driving, Mercedes-Benz has already pioneered driving assistance systems, such as adaptive cruise control, blind spot and lane keeping assistance. The next step is highly automated parking and driving where the driver and the occupants gain a benefit in one of the most expensive values: their own time. The therefore increased reliability stems from the now redundantly available electric power supply. Previous vehicle powernets consisted of an energy storage unit, usually a lead acid battery, an energy source or power supply, the alternator or a DCDC voltage converter for hybrid or electric vehicles to supply all electrical consumers. Since driving assistance systems enabling partially or highly automated driving are increasingly taking over the driver's control tasks, safety and availability requirements towards the electrical energy supply were enhanced for normal and single fault operation modes that improve the overall system reliability.

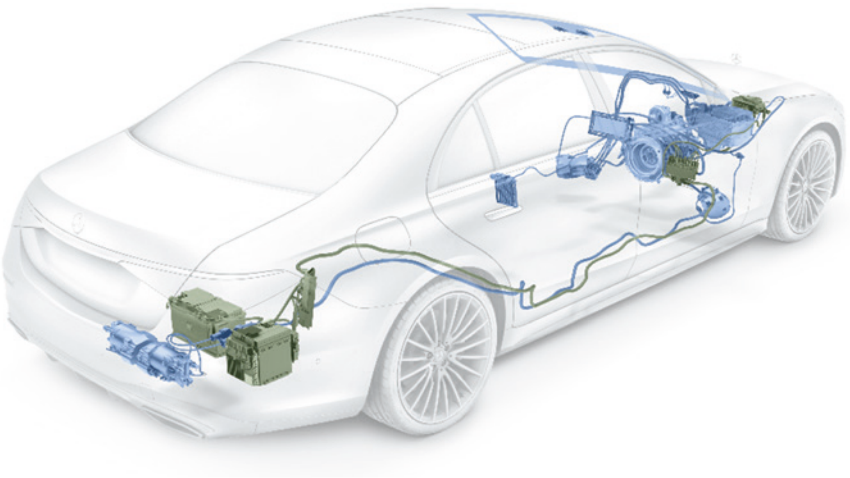

Fig. 5. Rear view of S-Class and secondary 12V powernet vehicle integration

A secondary power supply situated in the rear of the S-Class (Fig. 5) extends the primary powernet system in a parallel branch. In order to supply safety-relevant electrical components with the required voltage these two independent channels operate in combination or selectively (Fig. 6). In the event of a fault or failure of the primary on-board electrical system, the secondary powernet system assumes the supply of these system components to bring the vehicle in a safe state, e.g. stopped and parked, whether automated or by means of a driver intervention. An additional DCDC converter and a parallel power switch ensure the required supply and charging of the secondary powernet system. This DCDC converter controls the charge retention of the secondary battery with an additionally integrated battery sensor (IBS) and supports the supply of the consumers on the secondary on-board electrical system during regular driving situations. The power switch controls the current flow from the primary to the secondary on-board electrical system upon request. Current flow from the primary on-board electrical system to the secondary powernet system is possible for charging purposes. In addition, the switch prevents the current flow in opposite direction, in order to keep a sufficiently high level of charge and thus an increased voltage level in the secondary powernet during normal operation. In an extreme driving situation, the energy requirement in the secondary on-board electrical system exceeds the performance of the separate DCDC converter. The secondary on-board electrical system will thus be coupled with and additionally supplied directly from the primary on-board electrical system.

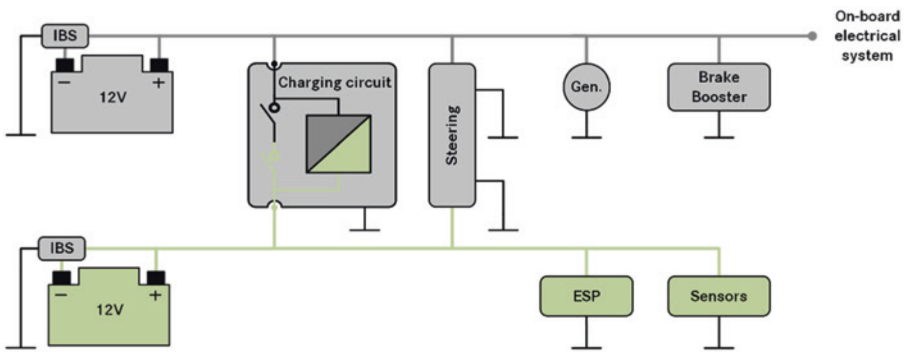

Fig. 6. Basic primary and secondary 12V powernet architecture

If undervoltage or overvoltage occurs in the primary or secondary on-board electrical system due to an error, the power switch between the redundant 12V on-board electrical systems will open in order to protect the higher priority driving functions, Fig. 6. With the separate DCDC-converter and the redundant secondary battery, the S-Class provides for Mercedes-Benz typical failure safety during competitive driving situations that are customer relevant.

5 Living – The User-centric Powernet System

The clearance of the electrical supply for comfort functions, such as infotainment or air conditioning, was previously defined via the so-called terminal state and thus dependent on the operating state of the combustion engine. Previously, the 12V generator supplied the convenience function as primary power source. The 12V battery supplies the engine start and the 12V power management prioritizes this with a terminal concept. The terminal state was previously divided with subtle differences in the following operating states. "Ignition off / key removed" as a general "Off" state. "Ignition on radio position" to make stationary functions such as the infotainment system and selected comfort features operable for a short time. "Ignition on" to enable diagnosis, comfort and driving function. "Start ignition" to activate the 12 V starter for conventional engine start. The customer triggers the state changes directly. These operating states design the general functional availability. To guarantee maximum availability of engine start, it was common to implement powernet shutdown scenarios, based on consumer/feature specific measures. An automated provision of comfort features and more flexibility with regard to the availability of functions as per customer request were only possible to a very limited extent due to the previously used mechanical elements. With the elimination of the ignition lock and the development of the KEYLESS-GO comfort package, we provided for the foundation of improved set-up and individualization of the operating states enabling customer-oriented automation – compare Fig. 7.

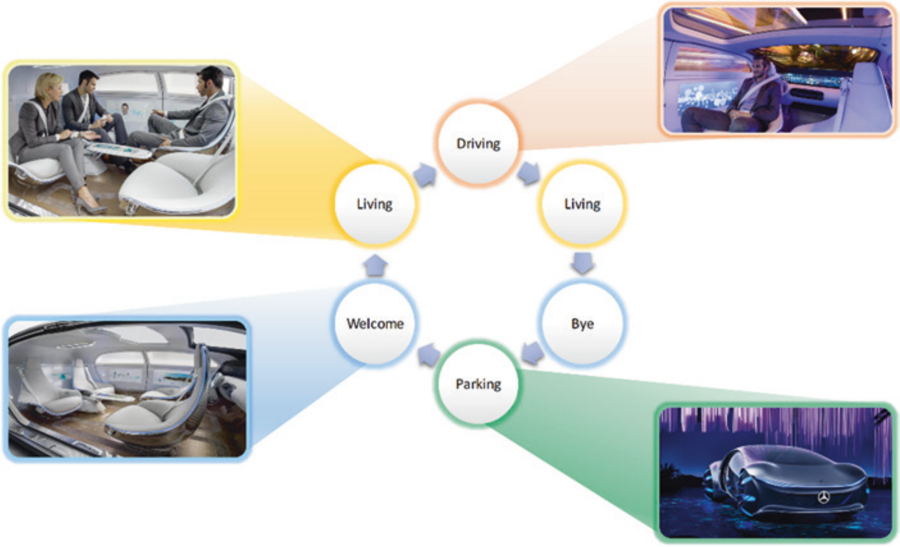

Fig. 7. "Always-On": comfort and driving functions in new vehicle states

We replaced the ignition lock by a start/stop button, which serves as control element between the operating states "features off" and "features on". For the engine start we used the operation of the clutch (for manual transmissions) or the brake (for automatic transmissions) when the start/stop button is pressed simultaneously. The remote control key provides the necessary authentication of all functional requests. Signal mapping was undertaken while maintaining the classic operating states, in order to ensure compatibility with older or existing systems and functions. The latest generation of our in-house E/E architecture (STAR3) and the introduction of either an integrated 48-V or a high-voltage powernet system enable energy optimization through partial networking, as well as specific recharging and charge-balancing strategies. With the new S-Class it is possible to provide our customers an extended spectrum of energy for comfort features before driving away and when stationary. From the customer's point of view broader availability of features is created by linking the powernet system control, e.g. with the automated key recognition functionality of the KEYLESS GO system and enables the S-Class user to be offered the desired and customizable combination of features at the right time and in the correct location. For example, it is possible to operate the power windows without "Ignition on". The definition of more customer-oriented and "ignition-independent" vehicle states serves as a synchronization point and enables the clearance of additional corresponding feature subgroups.

Mercedes-Benz can provide its customers with convenience functions immediately and even automatically thanks to further technical developments. The introduction of multi-voltage and secondary powernets, the inclusive additional energy storage systems and the definition of sub-networks for efficient use of the energy result in a greater range of options. For this purpose, the battery of the higher voltage level, 48V or HV, provides energy to the 12V level. Being "always on" with your S-Class is a state-of-the-art customer request; Mercedes users expect comfort functions to be available at all times. Considering two goals our implementation facilitates the immediate necessary clearance of features automatically and optimizes energy efficiency through integrated networking and power-down features.

6 Vehicle States

Focusing on customer user stories the new operating states were developed from the classic terminal stages, which were originally coupled with the operation of the ignition lock or start/stop button. "Parking" defines the power-down status of a parked vehicle. Energy conservation was optimally designed under the given boundaries to further extend power-up availability. The "Welcome" state will start as soon as a customer is identified to be in the vehicle environment via his key. Staging scenarios and function boot-up runs will activate in this state to offer the customer a greeting and to prepare further feature content for the subsequent stay in the vehicle. As soon as the vehicle detects the customer in its interior, it activates the "Living" state. It automatically and immediately offers a range of customizable features. Furthermore, a "Silent" setting can be activated, e.g. in order to offer customers extended electric driving range or to safe-guard the vehicle engine's starting ability. "Driving" is the scenario in which the vehicle is ready to drive and completely activated. Finally, the "Bye" state offers the user a farewell, initiates the power-down and shuts down the vehicle after the processing of all necessary functional and diagnosis after-runs. Especially the new vehicle states leading up to and following the "Driving" state are characterized by different and very specific power and energy requirements relevant to the design of the on-board electrical system – compare Fig. 8. The central 12V powernet management system controls the selective powernet actuation in the states "Parking", "Welcome", "Living" and "Bye".

Fig. 8. Power requirements in new vehicle states

7 Partial Network Operation

In order to save energy in the stationary phases, individual control units or subnetworks can be shut down through selective networking in the new Mercedes-Benz E/E architecture. The implementation of the AUTOSAR standard can control the partial network clusters with specific network management messages. One example for partial networking is the recharging feature of the 12V, 48V and HV power net. By only powering the control units, which are required for this feature the energy efficiency increases dramatically. Even the transmission of the batteries' state-of-charge information and operation state do not depend on the complete network to be awake, thus powering only the necessary components. Furthermore, if the customer only uses the infotainment system in the vehicle state "Living", the S-Class powernet will only supply this networking domain with energy. Other subnet clusters will automatically be activated if necessary, Fig. 9.

Fig. 9. Full and partial powernet activation

With this next step in powernet technology and innovation, Mercedes-Benz sends its new S-Class efficiently and well equipped on its resource-friendly and luxurious journey.

A Cross-domain System Architecture Model of Dynamically Configurable Autonomous Vehicles

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Abstract. The development of a dynamically configurable autonomous vehicle is subject to a high degree of complexity. This complexity is further intensified by usually domain-specific thinking and document-based development, leading to difficulties in managing the development processes. Therefore, there is a need for manageable and cross-domain approaches in the development of vehicle systems. For this purpose, Model-based Systems Engineering (MBSE) proposes an approach for modeling systems architectures with the necessary views for the development of vehicles. This contribution presents accordingly a cross-domain system architecture model in the sense of MBSE using the example of a dynamically configurable autonomous vehicle (DCAV) and highlights the resulting advantages for the development process. A DCAV includes an electrically and autonomously driven platform and exchangeable add-on capsules for different use cases. The system architecture model provides here a development environment where requirements on the DCAV, its behavior, and structure as well as their interrelations are described, structured, and unified at several levels for different use cases (e.g. passenger transport). In this way, a comprehensive basis for various development activities (e.g. function-oriented modularisation) is established, which at the same time indicates the great potential of system architecture models for the development of future vehicles.

Keywords: System Architecture Model · Model-based Systems Engineering · Dynamically Configurable Autonomous Vehicles

1 Introduction

According to current trends, future vehicle concepts will be characterized by a high degree of automation and flexibility [1]. Thus, there is a demand for vehicles with

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modular designs and adaptability to changing customer requirements during usage. Here, dynamically configurable autonomous vehicles (DCAV) provide autonomous driving and adaptability for changing use-cases during their usage. Consequently, DCAV promise high potential for new mobility solutions, sharing concepts, services as well as the reduction of traffic density in urban areas [2]. A major challenge for the realization of DCAV is the complexity of their development process. The complexity is characterised in particular by the variety and changeability of user needs as well as the internal variety of the system at different levels. Here, a particular challenge emerges in the handling of development-relevant data, for example regarding requirements, functions, or components. Developing this type of technical system requires approaches that facilitate transparent traceability and handling of development data for multidisciplinary engineering environments. Here, Model-based Systems Engineering (MBSE) proposes an approach for the structured documentation, handling, and communication of development data using models [3]. In this way, MBSE enables tailored views for the development of complex systems. Ultimately, MBSE provides a high potential to manage the complexity in the development of DCAV in the sense of Systems Engineering. Therefore, we raised the question of how to structure a "cross-domain system architecture model" in the sense of MBSE to support the development of dynamically configurable autonomous vehicles. For this purpose, this contribution initially introduces future mobility scenarios where DCAV constitute high relevance and offer significant potential. In addition, the development of a DCAV by the Automotive Research Centre Niedersachsen is introduced, which will set the example for the developed system architecture model. Following this, an overview of the development process of a DCAV is presented. Based on this, the newly developed system architecture model in the sense of MBSE is introduced, which supports cross-domain development of DCAV. Lastly, a conclusion of the results is presented, and an outlook for further steps given.

2 Dynamically Configurable Autonomous Vehicles in Future Mobility System Scenarios

In order to specify the frequently used term "The future of mobility", initially a picture of a future mobility system needs to be described. Here, a mobility system is the aggregate of all transport carriers and participants, the relevant infrastructure (both roads and traffic management systems, but also various forms of charging infrastructure) and all software systems and applications that are relevant for the operation or implementation of mobility services [1].

The scenarios that will take place in such a system in the future can be mapped by using factors from the social, technological, economic, ecological, and political sectors [4]. Based on global megatrends that are emerging, there are technological trends, changing customer wishes or preferences, as well as divergent legal requirements, which influences, push or inhibit each other. The key mobility trends are autonomous driving, electrification of the powertrain, and the digitalization of the vehicle, which enables connectivity between vehicles and with their environment. These trends in turn represent strong drivers and preconditions for enabling autonomous driving. [5]

Before we can clarify the question of how the concept of DCAV are within this mobility system, it is important to first describe the scenario, in which the surrounding system and the relevant boundary conditions for the use of DCAVs are depicted.

In this context, the depicted scenario is initially referring to the Central European region. The specific time in which this scenario takes place is currently irrelevant. It is much more important that essential legal and technical prerequisites are fulfilled. A decisive precondition as an enabler for autonomous driving is the existence of a legal basis for public areas. For this, at least automation level 4 (high automation according to SAE J3016) must be achieved. Furthermore, essential questions of liability in the event of possible accidents, as well as rules in mixed traffic situations, must be clarified. Decisive uncertainties that have a significant impact on the number of vehicles interacting in the mobility system are the driving behavior of the users (individual vs. sharing) as well as the intelligent connectivity of the entire mobility system. In addition to the necessary data infrastructure, a sufficient charging infrastructure must be available for electric vehicles.

A special focus on the scenario is facilitated by the AutoMoVe project of the Automotive Research Centre Niedersachsen (NFF) [6]. Here, the mobility system in Lower Saxony, which is a large state with an inhomogeneous population density is described. In addition to urban use cases, mobility solutions for rural areas are also required in this context. This focus on Lower Saxony gives an initial exemplified overview of the relevant descriptors for future scenarios. However, there are possible aspects that are difficult to estimate: For example, the Corona pandemic currently shows how unforeseen events can accelerate or inhibit trends. Due to the increased risk of infection and the related fear, the willingness to use sharing services or public transport decreases dramatically. The basic idea of car sharing is motivated by the rising population density in urban metropolises. The constant increase in the number of vehicles in cities can be slowed down or even reversed by car-sharing services. Coupled with the use of autonomous driving, there is the possibility that the vehicles will continue to move independently even after the associated end of use. At the same time, an obvious problem of urban areas results from increasing e-commerce, which in turn leads to more deliveries, more delivery vehicles, and thus an additional increase in the density of transport vehicles.

But what if the vehicles could not only be shared by several users, but the same vehicle could also be used for several use-cases (e.g. passenger and goods transport)? Dynamically Configurable Autonomous Vehicles offer this possibility. These are highly modular vehicles enabling a reconfiguration during actual use stage of the vehicles. In addition, they are dividable vehicles composed of a universally usable platform and exchangeable modules that allow their usage as people movers or delivery vehicles at different times, but on the same platform. Popular examples are the Snap, Microsnap, and Metrosnap concepts from Rinspeed, Vision Urbanetic from Daimler, and U-Shift from DLR [4].

For this reason, the project AutoMoVe (Fig. 1) aims the development of a DCAV consisting of different modular capsules for variable use cases based on an universal platform. In addition to the use case of inner-city cargo transport, which is already being researched in the project Van Assist [2], another classical relevant application is the use case of a people mover. Here, a fully automated and electrically driven platform PLUTO (Platform for Automated Future Urban Mobility and Transport) by the Institute for Vehicle Technology of the NFF is used. The platform serves as a starting point for the development of the DCAV.

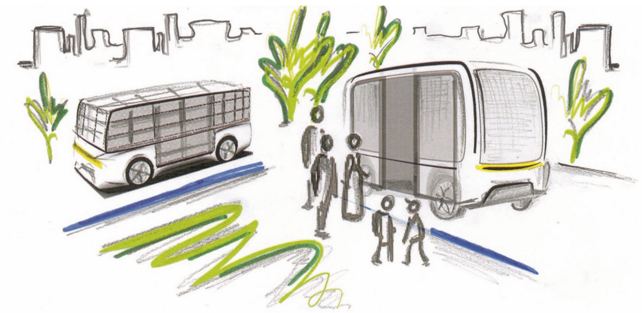

Fig. 1. AutoMoVe – DCAV with different use cases. (© Petia Krasteva, TU Braunschweig)

A basic specification addressed to the capsules is whether they are used actively during the connection on the platform or whether the use occurs after disconnection. Regarding the field of urban logistics solutions, an active vehicle for the delivery of food orders (home delivery) or a passive packing station could be mentioned as examples. Another fundamental attribute of modular vehicle concepts is the location of the exchange mechanism and whether it is permanently connected to the platform or are externally assigned to the capsules or the surrounding infrastructure. These application possibilities are complemented by the possible use of vehicles in the field of mobile services, such as waste disposal or street cleaning. In order to ensure 24-hour operation of the platform, these applications are very attractive, as they can be applied beyond regular times for passenger or goods transport. [2]

In cooperation with the project partner Formherr Industriedesign, an initial concept for a people mover was developed. The concept (Fig. 2) is intended to connect the Automotive Research Centre Niedersachsen (NFF) with the main campus of the Technical University of Braunschweig and should be able to transport up to six students.

Fig. 2. Concept of the DCAV "NFF-Peoplemover". (© Formherr Industriedesign)

This kind of complex system with different use-cases, changing requirements, cross-domain nature poses major challenges in the development process. Here, developers need to design solutions in collaborative environments with the same objectives and a unified understanding.