Many functions provided by electric/electronic (E/E) systems of modern vehicles are associated with the classic powertrain, chassis, body and multimedia domains. As a result of the advance of new technologies in the vehicle, however, domains such as driver assistance and connectivity are gaining tremendously in importance. Completely new functions are emerging here that are no longer limited just to the vehicle but are also provided in the backend outside the vehicle. Such a complex network of functions and ECUs can be handled much more easily if well-founded design decisions can be made during the design concept phase (Figure 1).

Functional and ECU Network

Most E/E functions fall under the categories of open-loop control, closed-loop control, monitoring or diagnostic functions. They interact with the mechanical vehicle components via sensors and actuators. Because the sensors and actuators are installed at different geometric locations in the vehicle, E/E systems are naturally geometrically distributed systems. Many functions are networked within a domain but are also networked with one another across domain boundaries. Driver assistance functions, in particular, are closely integrated with the functions of the powertrain, steering and brake systems. For this reason, the distribution and assignment of functions to the ECU network represents a major degree of freedom in the design – and is thus an important design decision. Practically all evaluation criteria of an E/E architecture are influenced directly or indirectly by the design of the ECU network and by the assignment of functions to ECUs.

The resulting requirements for the wiring harness or the onboard communication are important criteria that must be taken into consideration early in the design process. Also there are many others: For one thing, the design criteria must be expanded to include offboard communication requirements. For another thing, driver assistance systems with cameras and radar sensors provide an environment model of the vehicle. Ethernet technology is increasingly being used here to realize the necessary transmission performance. If, as expected, Ethernet establishes itself as the future standard that is used in combination with CAN, LIN and FlexRay, enormous technical consequences for the
E/E architecture will arise. Networking will no longer be limited to the vehicle. Rather, it will also include functions provided outside the vehicle. This, in turn, will result in increasing security requirements for the E/E architecture since the vehicle is connected to communication partners and services via wireless “over the air” connections. The trend toward automated driving, which entails increasing safety requirements, is another challenge, as is the growing number of vehicle variants and the associated increase in importance of product line, variant and platform approaches. Even the widely accepted AUTOSAR platform for the classic domains is subject to change—the AUTOSAR Adaptive Platform is currently being discussed for the new domains.

**Defining the Most Suitable E/E Architecture**

How can all these aspects come together in the architectural design? How can the most suitable E/E architecture be defined for this? It is obvious that the complete system must be considered. To design and optimize only a part of the system will result only in a local optimum. Moreover, the feasibility of new concepts must be evaluated early on to reduce risks in later series development. Finally, the optimization goals of a “good” architecture must also be defined (Figure 2). These start with the “hard” goals that are derived from the goals of the overall vehicle, such as cost barriers, weight specifications, installation space and geometry specifications and maximum permissible electricity consumption values. These goals influence the E/E components from the hardware perspective and also influence the wiring harness (Figure 3). The architecture optimization is not limited to this, however. There is another group of goals that are derived from the implemented vehicle functions. These include real-time requirements for buses and ECUs and all diagnostic and service requirements. Bus load limitations and safety and security requirements are also in this group.

E/E architectures are ultimately designed not just for one individual vehicle. Rather, a portfolio of vehicles, vehicle variants and vehicle options must be supported by an E/E architecture. For this reason, the other essential goal category of product line requirements takes into account:

- Variants and options
- Expected quantities and proportions of vehicles with the equipment
- Function-oriented decomposition or component-oriented reuse
- Building blocks with dedicated use strategies for components and subsystems

Here the solution is always a compromise between two extremes. On the one hand, there are special E/E components for a dedicated variant with low production quantities. On the other hand, there are general E/E components for multiple variants with high production quantities but with additional costs for possibly unneeded functionality. The definition of the “best” E/E architecture is thus a non-trivial multidimensional optimization problem.
In the PREEvision model, the abstraction layers, from the geometry layer with installation locations and routing paths to the wiring harness layer and electric circuit layer to the ECU network layer, are represented in the vertical direction. The software and communication details are modeled in parallel with that. Hardware and software aspects are described abstractly in the layer of the logical function architecture; an even greater degree of abstraction occurs on the layers for requirements and customer needs.

Model-Based Approach with PREEvision

To take into consideration all relevant aspects of an E/E architecture, PREEvision supports a model-based approach. That is, all aspects of an architecture are modeled in one integral approach: network and functional distribution; hardware, wiring harness and geometry; communication and software; and all functions, features and requirements. In order to handle complex E/E systems, PREEvision follows three proven systems engineering principles – abstraction, decomposition and reuse – and supports the modeling of product lines and product variants with various model layers (Figure 4).

Figure 2: Optimization goals of an E/E architecture.

Figure 4: The abstraction layers in the PREEvision model
features. The horizontal direction of the PREEvision model supports the decomposition. Hierarchy concepts that can be modeled bottom up or top down are available in each layer. The third direction is orthogonal to the other two directions and enables reuse and variant concepts on each model layer and hierarchy level.

The engineering data model is inspired and shaped by the relevant automotive standards: RIF and ReqIF for requirements, customer functions and test cases; AUTOSAR for the system, software and communication design; KBL and VEC for wiring harness and geometry specifications.

An additional benefit arises from the logical function architecture that is abstracted from the implementation in hardware and software. For many vehicle functions, this layer remains stable over many years, while the hardware, software and communication technologies for their implementation change from one vehicle generation to the next. All these layers are interconnected via so-called mappings. Safety aspects are supported by safety analyses such as HARA (Hazard and Risk Analysis), FMEA (Failure Mode and Effects Analysis) and FTA (Fault Tree Analysis) and performed on the existing product line model. The integrated model-based approach supports the single source principle. The model can be checked for inconsistencies and completeness.

With the customer feature model, a valid selection of customer features for a vehicle variant is possible that is connected to the corresponding artifacts of all other layers. As a result, an E/E architecture can be derived for selected variants and evaluated using customized optimization criteria (metrics). PREEvision supports teamwork with a collaboration platform in which a team of architects can work in parallel on one product line. All architecture artifacts are subject to version management and are linked with tickets for coordinated change and release processes.

The model-based architecture development generally does not start from scratch but rather is a further development of existing architectures. Optimizations or innovations are thereby taken into account for the next architecture generation. Typical steps here are the import of data of the predecessor architecture and its integration and validation. The innovations for the next architecture generation are then conceptualized; various alternatives are evaluated and compared with user-defined optimization goals. When the best solution is determined, the architecture is exported as the basis for the series development. In this way, a high concept quality for new E/E architectures is ensured from the outset. However, architecture development is not just an activity before the start of the development project. Rather, it is continuously performed and evaluated during series development.

![Figure 5: Multidimensional evaluation of an architectural design.](image)
Evaluating and Optimizing the Architectural Design
In practice, the E/E architecture is evaluated on the basis of typical vehicle configurations and equipment variants. Often, three configurations – basic equipment, top-selling vehicle and full equipment – are used for this (Figure 5).

The basic equipment must be supplied at a low price – the cost-benefit ratio is the dominant design criterion here. The top-selling vehicle is defined as the vehicle with the highest anticipated production quantities and whose functionality must be provided for a competitive price. In the full equipment category, all E/E systems and options must work together from the perspective of all design criteria and boundary conditions such as weight, installation space, bus load, power consumption, etc., must be satisfied. The expected quantities are low and the vehicle price is high – cost criteria are not dominant here.

The optimization goals are thus not only multidimensional but they are also different for various equipment variants and vehicle configurations. In addition, they change over time such as, for example, when optional vehicle functions are rarely ordered at first but later increase in demand and even become basic equipment. For these reasons, there is currently not a generally accepted optimization criterion. Rather, the optimization strategy is viewed as an intellectual property of the vehicle manufacturer.

For this reason, PREEvision provides access to the complete data model through scripts (metrics), and the user can thus flexibly determine its optimization strategy. Over 10 years of successful use of this concept in projects at leading vehicle manufacturers around the world speak in favor of it. Large vehicle product lines here encompass millions of artifacts; the data model, engineering tools and metric interfaces undergo continuous further development in close cooperation with users.

Solid Architecture Work with Optimal Tool Support
A model-based E/E architectural design must enable the many new functions of the next vehicle generations. Here, the driver assistance and connectivity domains, in particular, are leading to major technical changes. E/E architects face the task of having to connect these innovations to the classic powertrain, chassis, body and multimedia domains.

In doing so, they must often meet multidimensional optimization goals. Approaches that consider only one category, such as the global vehicle goals of cost, weight and installation space, are not adequate.

The growing functional scope of future E/E systems is further raising the importance of solid architecture work and orderly architecture decisions and architects need a tool that supports them in all relevant aspects. PREEvision provides this support with versatile functions and also takes into account the latest technologies and development standards of the automotive industry.

Optimization criteria can be calculated for selected equipment variants and can be flexible defined. An integral consideration of the model-based approach is that architecture work is an ongoing process that takes place in parallel with series development and requires continuous close communication among all parties involved. This is just one of the reasons that PREEvision is an eminently suitable tool for design and optimization of modern electric/electronic architectures.

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