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OPTIMIZATION APPROACH FOR FUNCTION-PARTITIONING IN AN AUTOMOTIVE ELECTRIC ELECTRONIC SYSTEM ARCHITECTURE

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1. Introduction

Automotive original equipment manufacturers (OEMs) all over the world strengthen their profitability and efficiency sustainably. Aiming to ensure competitiveness, the majority of OEMs tries to diversify horizontally and vertically.

In addition to traditional series, OEMs focus on profitable product niches and new service concepts (e.g. car sharing, charging infrastructure for electric vehicles or value added services (VAS) like BMW Connected Drive). Besides their activities in top line improvements respectively [Ehrlenspiel et al. 2010], OEMs focus on adjustments on the costside. This is done in the context of general transformation programs and the additional economic optimization of the product structure overall profitability [Lindemann et al. 2010]. In particular automotive architecture and modular construction sets are in the focus of these economic optimization efforts [Reiner and Krieger 2011].

2. Challenges and motivation

In the course of their efforts, OEMs are facing diverse challenges. Structuring activities - as introduced above - are fundamental for the optimization. In this context, next to the complete geometrical architecture (automotive architecture), the electric electronic (EE) architecture plays a decisive role. The application of EE components is essential for the functionality of modern automobiles. These EE components fulfill specific functions or provide services in all areas, such as dedicated functions in chassis, power train, body, driver assistance, infotainment and security [Broy et al. 2009].

In addition, up to 90% of all automotive innovations are derived from or at least are enabled by EE components respectively EE functions. In this context, the number of electronic control units (ECUs) in luxury cars increased by more than 30% within the last five years [Robert Bosch GmbH 2007], [Broy et al. 2009], [Reiner and Krieger 2011]. This leads to a considerable increase of complexity of in the EE architecture and the resulting EE overall system [Reiner and Krieger 2011].

Furthermore, the growing number of vehicle derivatives and the rapid increase of new functions represent considerable multipliers of complexity within the automotive EE development [Bentley 2011]. This article assumes that an OEM uses only one EE architecture for all its series in order to handle complexity and realize economies of scale.

The objective of this article is to develop a cost optimization approach for the function-partitioning of EE-systems-architecture (EE-SA) by using technical and economic factors. Thereby, the consideration of the EE overall system aims at making the existing complexity controllable. The result of the optimization approach forms the basis for structuring the future EE modular construction set development and its integration into an EE-SA.

Next, the basic concepts and terms are introduced. After that the research approach is explicated. Based on that, the artifact of the optimization approach for the partitioning of an EE-SA and the approach itself will be explained. The article is an intermediary result. The approach and its findings are open for discussion to achieve further improvement and validation within the scientific environment.

3. Basic concepts and terms

A EE-SA is defined as the logical and physical partitioning of all EE functions on ECUs within the system architecture, including the interface topology, the bus systems for data communication and the management of the energy system architecture [Robert Bosch GmbH 2007], [Broy et al. 2009].

Partitioning is the localization of EE functions with their corresponding HW and SW on ECUs (cf. Figure 1). Generally EE functions can be partitioned within an EE-SA on any ECUs. In the context of this specific optimization approach EE functions are partitioned either on the Central-ECUs (contains multiple EE functions) or on Single-ECUs (contain only one EE function) as explained below.

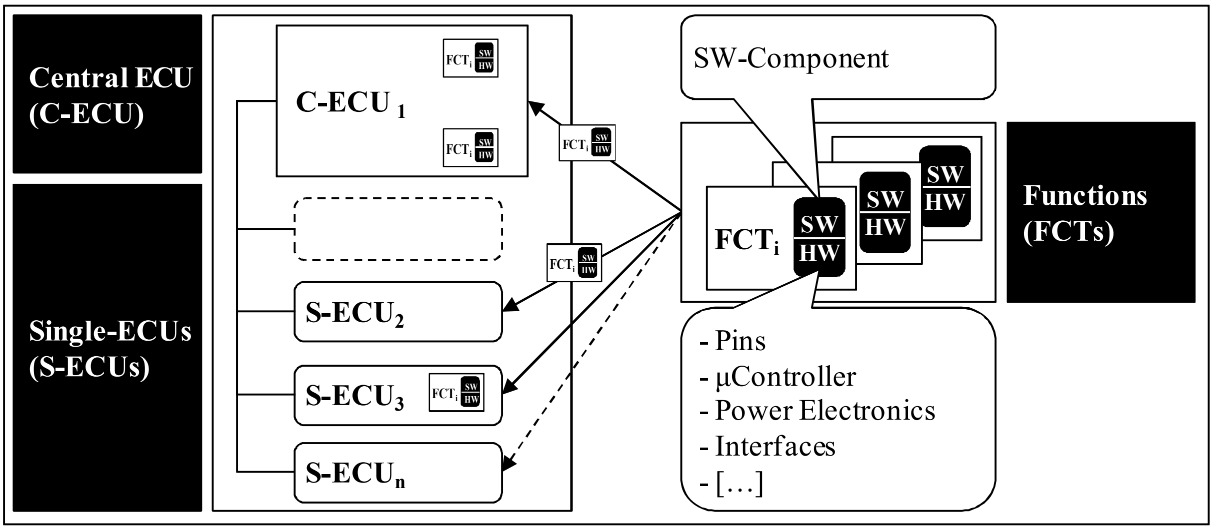


Figure 1. Function-partitioning on ECUs

The topology of an EE-SA describes the network structure of system components. In the automotive industry, connection structures in use are the ring, star and bus structure as well as their combination [Robert Bosch GmbH 2007].

The energy system architecture as part of the EE-SA provides sufficient energy for all EE components in the vehicle. It is composed of generators, transformers and energy storage. The additional task is to compensate the minimum and maximum load in the EE-overall-system (EE system stabilization, e.g. for start-stop-systems) [Broy et al. 2009].

ECUs are the central computing and control units of an EE-SA. They fulfill essential tasks of the vehicle control system, the vehicle regulation, its monitoring as well as the diagnosis. All have to be processed within the EE-SA [Broy et al. 2009]. ECUs consist partly of corresponding hardware (HW) and software (SW). The main components of the HW are embedded microcontrollers and memory (read-only memory (ROM), random-access memory (RAM) and Flash Memory), primarily localized on the circuit board [Robert Bosch GmbH 2007].

As mentioned above, this article distinguishes between Central-ECUs (C-ECUs) and Single-ECUs (S-ECUs) (cf. Figure 1) within one domain of the EE-SA. C-ECUs are hierarchically superior to the S-ECU (Master-Slave-Relation). As figure 1 shows one domain contains one C-ECU and multiple S-ECUs. C-ECUs operate as central gateways. Additionally they contain multiple EE functions along with their according HW and SW. These EE functions are standard in all model series and its vehicle derivatives. For the reasons of simplification, an S-ECU contains only one function with its related HW and SW components. These EE functions are standard in just a number of all model series and its vehicle derivatives (mainly within the luxury segment). Thereby one S-ECU can e.g. be easily be standardized, replaced or removed. Thus, this article assumes that the HW comprises passive or active semiconductors and the SW used is to be developed according to the Automotive Open System Architecture 4.0 Standard (AUTOSAR).

An ECU can be a modular construction set. A modular construction set consists of SW, HW and electro-mechanical components. It enables a comprehensive implementation across all model series by special planning, design and the coverage of EE functions. At the same time, it achieves the differentiation that customers demand. Furthermore it aims at sustainable, long-term and model series-across planning of a range of EE functions, focusing on the overall economic optimum and additionally the termination of allocation.

Taking all into account, ECUs in a vehicle create a highly complex EE system for which appropriate connection technologies are necessary. ECUs communicate with each other and with other EE HW components (e.g. sensors and actuators) [Broy et al. 2009]. They communicate via deterministic bus systems (Flex Ray, TTP (Time-Triggered Protocol)) or priority controlled bus systems (LIN (Local Interconnect Network), CAN (Controller Area Network), MOST (Media Oriented Systems Transport)) [Robert Bosch GmbH 2007].

4. Research approach

The research approach used for the development of the optimization approach is based on Design Science. The core of this design oriented approach is the creation and configuration of context-based artifacts to solve a problem [Simon 1996]. This problem has to be of a practical relevance and has to be characterized as being useful in practice [Hevner et al. 2004]. The procedure within Design Science can be seen as the search for an optimal solution using five steps [Vishnavi and Kuechler 2004].

It starts with the perception of the problem and continues with the development of a proposal for solution. This proposal has to be realized subsequently (Step: Development). The next step is the evaluation of the developed artifact. Using iteration as a method, a continuous improvement has to be reached with every stage of development. Thus, the number of iterations in not defined. The conclusions of every step of the evaluation process are integrated in the next evaluation step. An artifact is considered complete when the originally defined problem is solved [Hevner et al. 2004]. An optimization problem can be such an artifact, just like it is in this article, whereas the solution lies within the improvement [Hevner et al. 2004]. The developed optimization approach (the artifact) has the necessary significant praxis relevance and is unprecedented. The current status of this optimization approach can be considered as “research in progress” within the evaluation step.

5. Optimization approach for function-partitioning of an EE-SA

5.1 Matters of consideration

Based on the objective (cf. chap.1) the question arises how an overall EE system needs to be designed to include all the required EE functions. Therefore, an optimization approach for the controlled partitioning of EE functions in a domain-structure based EE-SA will be developed in this chapter.

The cost optimization approach sets the research-framework for the design of the optimization approach. Since the optimization approach fundamentally differentiates between development costs (DC) and manufacturing costs (MC), these two cost categories need to be ascertained for all EE functions. DC are quantity-independent and result of the development of an ECU including all related HW- and SW-components (generally as a one-off expense). MC include all costs for materials and production of an ECU and are quantity-dependent [Ehrlenspiel et al. 2010], [Lindemann et al. 2010].

An EE-SA is divided into a number of domains (cf. Figure 2). Each domain covers a related range of EE functions (e.g. chassis, power train, infotainment or security functions). Every EE function is assumed to be genuine, i.e. a single EE function can be assigned to one domain exclusively.

Moreover, only basic EE functions are considered. EE basic functions are the sum of all EE functions that are serially included in every model series of OEMs. For reasons of simplification, optional equipment will not be considered in the optimization approach. This would require the additional consideration of the factor take-rate (selection rate of optional equipment by the customer).

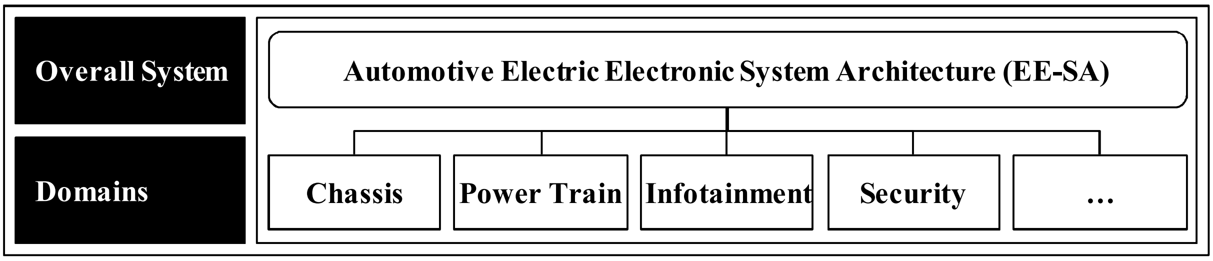
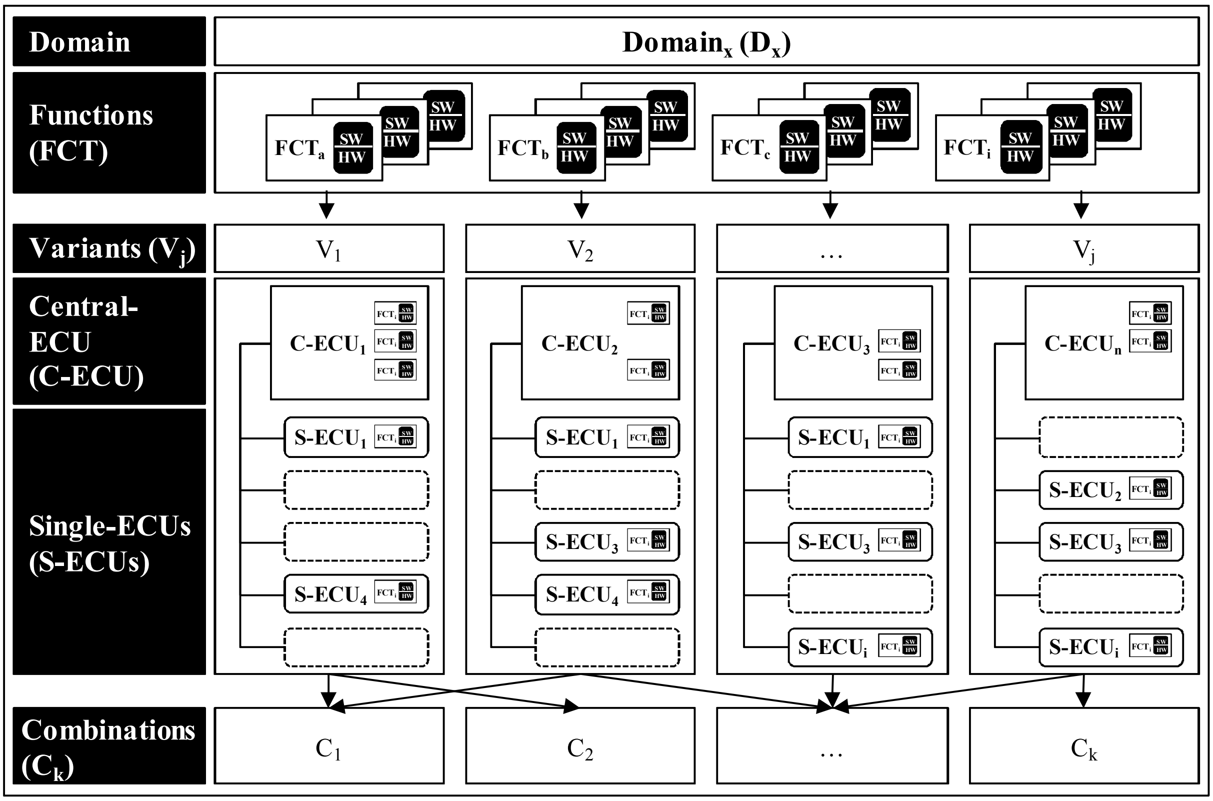


Figure 2. Domain structure of the EE-SA

As shown in Figure 1 and 3, the EE functions consist of SW and HW and are located in ECUs. (cf. 1.2). As part of the optimization approach the domain-specific EE functions are either located in the C-ECU or the S-ECUs (cf. Figure 1 and Figure 3).

Figure 3 illustrates the basic solution space for optimizing a domainx. Within the allocation of domain-specific EE functions on the C-ECU and the S-ECUs a multiplicity of variants (v) are generated per domain. Each variant can be characterized by its specific allocation of EE functions on the C-ECU and the S-ECUs. Therefore, depending on the variant, the number of S-ECUs can vary. Multiple allocations of one EE-function within a variant is not possible, sc. an EE-function can never be located on one C-ECU and an S-ECUs at the same time.



FCT:	Functions per domain with software- and hardware-components.
V_j:	Variants of one domain. The number of variants depends on the amount of functions.
C-ECU:	Central-electronic control units with multiple functions.
S-ECU:	Single-electronic control units with only one function.
C_k:	Combination of variants per domain.

Figure 3. Domain design of the EE-BNA combinations

Given that the EE-SA has to be commonly used across all model series of an OEM, it is reasonable to allow multiple variants within the C-ECU optimization. This results in a number of possible combinations (C_k) of C-ECU variants, for which the costs are accounted accurately. Every possible combination includes a certain number of variants. The optimization of each domain focuses on the identification of the cost-optimal combination of C-ECU variants with its specific S-ECUs. The application of the optimization approach generates a specific optimum for each domain separately. The combination of the optimized domains results in the EE system.

In summary, the following constraints are taken into account within the optimization approach:

- An OEM implements only one EE-SA for all model series.
- The EE-SA contains a specific number of domains that need to be defined.
- Each domain consists of one C-ECU and multiple S-ECUs and covers a specific range of EE functions.
- The allocation of an EE function within more than one domain is not permissible.
- Only basic EE functions (functions that are serially included in every model series) are considered, i.e. optional equipment will not be considered in the optimization approach.
- A C-ECU can contain multiple EE functions.
- A S-ECU can contain only one single EE function.
- A multiplicity of variants is possible per domain.
- The cost-optimal combination per domain consists of C-ECU variants with specific S-ECUs.

5.2 Elements of the optimization approach

The optimization approach for the controlled structuring of the EE-BNA will be described in two steps. In the first step, DC and MC are derived and accounted for all possible variants V_j of a C-ECU combinations c_k including its specific S-ECUs per domain. The combination of the optimized domains to one EE system follows in the second step.

5.2.1 Logic of the calculation of the DC/MC cost structure within a combination c

The procedure within the cost optimization approach is to calculate the DC and MC for the C-ECU and S-ECU of every variant possible per domain (cf. Figure 4).

Cost Category	Development Costs (DC)		Manufacturing Costs (MC)	
Cost Type and Factors	Core Costs DC	Factors DC	Core Costs MC	Factors MC
Parameters	Variant Resource Use Simulation/Testing	Development-Cooperations	Variant Resource Use Number of Units	Competition between Suppliers Purchasing-Cooperations
Central- ECU (C-ECU)	$CCDC_{c,v}$ (T, CPU, RAM, ROM, FLASH)	$DCOOP_{\alpha}$	$CCMC_{c,v}$ (N, CPU, RAM, ROM, FLASH)	CBS_{γ} $PCOOP_{\beta}$
Single-ECUs (S-ECUs)	$CSDC_{c,f}$ (T, CPU, RAM, ROM, FLASH)	$DCOOP_{\alpha}$	$CSMC_{c,f}$ (S, CPU, RAM, ROM, FLASH)	CBS_{γ} $PCOOP_{\beta}$

$CCDC_{c,v}$: DC core costs of a C-ECU dependent on resource use and simulation/testing.
$CSDC_{c,f}$: DC core costs of a S-ECU dependent on resource use and simulation/testing.
$DCOOP_{\alpha}$: Factor development-cooperation.
$CCMC_{c,v}$: MC core costs of a C-ECU dependent on variant, resource use and number of units.
$CSMC_{c,f}$: MC core costs of a S-ECU dependent on variant, resource use and number of units.
CBS_{γ} : Factor competition between suppliers.
$PCOOP_{\beta}$: Factor purchasing-cooperation.

Figure 4. Structure of the cost categories DC and MC

As shown in Figure 4, the cost categories DC and MC are calculated via their core costs (core costs DC and core costs MC) and specific influencing factors (factors DC and factors MC).
The core costs and their factors differ between C-ECUs and S-ECUs since the complexity of C-ECUs is unexceptional higher. The respective parameter values used within the optimization approach based on semi-structured interviews with experts. The precise derivation of the parameter values is very complex. Therefore, for the reason of simplification, the parameter values will not be verified within this article.
To gain a better overview, Table 1 and Figure 4 include the definition of the variables used in the optimization approach.

Table 1. Variables of the optimization approach

VARIABLE	TERM	CAUSE VARIABLE	
D_x	Domain	$x \in \mathbb{N}$	$D_{ges} = \{D_1, D_2,\ldots,D_x\}$
f_i	Function	$i \in \mathbb{N}$	$F = \{f_1, f_2,\ldots,f_i\}$
v_j	Variant	$j \in \mathbb{N}$	$V = \{v_1, v_2,\ldots,v_j\}$
c_k	Combination	$k \in \mathbb{N}$	$C = \{c_1, c_2,\ldots,c_k\}$

The overall costs ($C_{DC+MC,Dx,c}$) of domain in a combination c is composed of the overall domain development cost ($DC_{Dx,c}$) and the overall domain manufacturing costs ($MC_{Dx,c}$) of a domain for the specific combination c (cf. equation (1)).

$$C_{DC+MC,D_x,c} = DC_{D_x,c} + MC_{D_x,c} \tag{1}$$

$C_{DC+MC,Dx,c}$	Overall costs per domain Dx for a specific combination c.
$DC_{Dx,c}$	Overall domain development cost for a specific combination c.
$MC_{Dx,c}$	Overall domain manufacturing costs for a specific combination c.

The calculation of the overall domain development cost and the overall MC of a domain is explained in the following. First, the calculation of the DC is going to be introduced. The DC core costs of a C-ECU ($CCDC_{c,v}$) are influenced by the combination c of C-ECUs, the variant v, expenses for simulation and testing T and the resource use of the central processing unit (CPU) and memory (RAM, ROM and FLASH).
Depending on the combination c and variant v, the factor development-cooperation ($DCOOP_\alpha$) is influencing the core costs of a C-ECU (cf. Table 2). There are three possible parameter values α. In the case of a typical development-cooperation on a C-ECU, the development cost, respectively the development expenses are being shared [Arnold and Eßig 1997]. Ideally, the cooperation partners can save up to 50% of the original costs ($DCOOP_1$= 0,5). In a different scenario, the possible savings of a development-cooperation are lower ($DCOOP_2$= 0,75). This is due to transaction costs. In case of no development-cooperation the factor does not influence the core costs of a C-ECU ($DCOOP_3$= 1).

Table 2. Parameter $DCOOP_\alpha$

PARAMETER	VALUE	INFLUENCE ON DC-C-ECU AND DC-S-ECU CORE COSTS $CCDC_{c,v}$
$DCOOP_1$	0,5	development-cooperation on a C-ECU/ S-ECU with 50% DC-savings
$DCOOP_2$	0,75	development-cooperation on a C-ECU/ S-ECU with 25% DC-savings
$DCOOP_3$	1	no development-cooperation on a C-ECU/ S-ECU

Multiplying the core cost of a C-ECU with the factor development-cooperation results in the DC of a C-ECU variant v in a specific combination c. The sum of all DCs of all C-ECUs in a combination c results in the overall C-ECU development costs $DC_{CECU,Dx}$ (cf. equation (2)).

$$DC_{CECU,D_x} = \sum_{v=1}^{V} CCDC_{c,v}(T, CPU, RAM, ROM, FLASH) \times (DCOOP_{\alpha}) \qquad (2)$$

$DC_{CECU,Dx}$	Overall C-ECU development costs of a domain D_x.
$CCDC_{c,v}$	Core costs of a C-ECU dependent on the combination c_k and the variant v_j.
$DCOOP_{\alpha}$	Factor development-cooperation dependent on the parameter values α.
v_j	Possible variants of a domain D_x.

The C-ECU combination c determines which functions are localized in S-ECUs. The DC core costs of a S-ECU ($CSDC_{c,f}$) are influenced by expenses of test and simulation T and the resource use of the CPU and memory. Development-cooperation can influence the core costs of S-ECUs ($CSDC_{c,f}$), as well. Analog to the $DCOOP_{c,v,\alpha}$, there exist three parameter values α (cf. Table 2).

The DCs of a S-ECU for a function f in a specific combination c are calculated by multiplying the core costs with the factor development-cooperation. The overall DCs of all S-ECUs of the functions F in the combination c ($DC_{SECU,Dx}$) are composed by the sum of all single terms (cf. equation (3)).

$$DC_{SECU,D_x} = \sum_{f=1}^{F} \mathrm{CSDC}_{c,f}(T, CPU, RAM, ROM) \times (DCOOP_{\alpha}) \qquad (3)$$

$DC_{SECU,Dx}$	Overall S-ECU development costs of a domain D_x.
$CSDC_{c,f}$	Core costs of a S-ECU dependent on the combination c_k and the function
$DCOOP_{\alpha}$	f_i.
f_j	Factor development-cooperation dependent on the parameter values α.
	Function of a domain D_x.

Combining both terms (2) and (3) results in the overall domain development cost ($DC_{Dx,c}$) for a specific combination c (cf. equation (4)).

$$DC_{D_x,c} = DC_{CECU,D_x} + DC_{SECU,D_x} \qquad (4)$$

In the following, the calculation of the DC is going to be introduced. The MC core costs of a C-ECU are determined by the combination c, the variant v and the use of resources of CPU and memory. In addition, the core manufacturing costs of a C-ECU variant v ($CCMC_{c,v}$) are influenced by the number of units $N_{c,v}$ which depend on the specific combination c of C-ECUs.

Depending on the variant v and the C-ECU combination c, the factor purchasing-cooperation ($PCOOP_{\beta}$) is influencing the core costs of a C-ECU. Comparable to $DCOOP_{\alpha}$ there are three possible parameter β (cf. Table 3). The MC savings through purchasing-cooperation are primarily realized by the experience curve effect. Depending on the general conditions and requirements, an increase in volume can lower the MC for the supplier (e.g. internal effect of an increasing capacity or economies of scale) [Arnold and Eßig 1997]. These effects can be forwarded (partially) to the OEM. With an increase in volume, the market power of the OEM is increasing, as well, which leads to a stronger bargaining position. In total, a savings potential of 5% to 10% of the MC is assumed, which is customary within the automotive industry.

Table 3. Parameter $PCOOP_{\beta}$

PARAMETER	VALUE	INFLUENCE ON MC-C-ECU AND MC-S-ECU CORE COSTS $CCMC_{c,v}$
$PCOOP_1$	0,9	purchasing-cooperation on a C-ECU with 10% MC-savings
$PCOOP_2$	0,95	purchasing-cooperation on a C-ECU with 5% MC-savings
$PCOOP_3$	1	no purchasing-cooperation on a C-ECU

Competition between suppliers (CBS_γ) is a further factor for the core cost of an C-ECU. There are three possible parameter values γ. In case of a significant market power by the OEM, the competition between suppliers can be beneficial for the C-ECU core cost of the MC (CBS_1 = 0,9). In another case the competition between suppliers does not affect the C-ECU core costs of the MC (CBS_2 =1). An oligopoly is an example for how little competition between suppliers can have negative effects on $CCMC_{c,v}$ (CBS_3=1,1) (cf. Table 4).

Table 4. Parameter CBS_γ

PARAMETER	VALUE	INFLUENCE ON MC-C-ECU AND MC-S-ECU CORE COSTS $CCMC_{c,v}$
CBS_1	0,9	competition between suppliers has positive influence on $CCMC_{c,v}$
CBS_2	1	competition between suppliers has no influence on $CCMC_{c,v}$
CBS_3	1,1	competition between suppliers has negative influence on $CCMC_{c,v}$

The sum of the MCs of all C-ECUs in a combination c results in the overall $CCMC_{c,v}$ of a combination. Multiplying the core cost of a C-ECU with the factor purchasing-cooperation and the factor for the competition between suppliers results in the manufacturing costs of a C-ECU ($MC_{CECU,Dx}$) variant v in a specific combination c (cf. equation (5)).

$$MC_{C-ECU,D_x} = \sum_{v=1}^{V} CCMC_{c,v}(N, CPU, RAM, ROM, FLASH) \times CBS_\gamma \times PCOOP_\beta \qquad (5)$$

$MC_{CECU,Dx}$	Manufacturing costs of a C-ECU of a domain D_x.
$CCMC_{c,v}$	Core manufacturing costs of a C-ECU dependent on the combination c_k and the variant v_j.
CBS_γ	Factor competition between suppliers dependent on the parameter values γ.
$PCOOP_\beta$	Factor purchasing-cooperation dependent on the parameter values β.

The C-ECU combination c determines which functions are localized in S-ECUs. The MC core costs of a S-ECU are determined by the combination c, the variant v and the use of resources of CPU and memory. In addition, the core manufacimituring costs of a S-ECU ($CSMC_{c,f}$) are influenced by the number of units $N_{c,f}$, which depends on the specific combination c of C-ECUs variants.

Purchasing-cooperation $PCOOP_\beta$ can have effects on the MC core cost of a S-ECU. Depending on the specific combination c and the S-ECU itself, there are three possible parameter values β (cf. Table 3) which represent the same effects as for the C-ECU purchase-cooperation. Alike, there exists the factor for competition between suppliers (CBS_γ) for S-ECUs with three possible parameter values γ (cf. Table 4). They represent a positive, neutral or negative effect on the $CSMC_{c,f}$.

The MCs of a S-ECU for a function f in a specific combination c are calculated by multiplying the core costs with the factor purchasing-cooperation. The overall MCs of all S-ECUs of the functions F in the combination c ($MC_{SECU,Dx}$) are composed by the sum of all single terms (cf. equation (6)).

$$MC_{SECU,D_x} = \sum_{f=1}^{F} CSMC_{c,f}(N, CPU, RAM, ROM, FLASH) \times CBS_\gamma \times PCOOP_\beta \qquad (6)$$

$MC_{SECU,Dx}$	Manufacturing costs of a S-ECU of a domain D_x.
$CSMC_{c,f}$	Core manufacturing costs of a S-ECU dependent on the combination c_k and the function f_j.
$CBS\gamma$	Factor competition between suppliers dependent on the parameter values γ.
$PCOOP_\beta$	Factor purchasing-cooperation dependent on the parameter values β.

The addition of equations (5) and (6) results in the overall MC of a domain D_x for a specific combination c (cf. equation (7)).

$$MC_{D_{x},c} = MC_{CECU,D_x} + MC_{SECU,D_x} \tag{7}$$

The overall costs ($C_{DC+MC,Dx,c}$) of domain in a combination c results from the addition of equation (4) and (7) (cf. equation (1)). This calculation has to be repeated for every possible combination.

5.2.2 Identification of the cost-optimal combination c in a domain D_x

The result of the calculation of overall costs in a domain is a set of combinations C of C-ECU variants v including the related costs (cf. equation (8)). This set allows to select the cost optimal combination c of C-ECUs and therefore obtains the cost optimal domain structure.

$$C = 2^V = 2^{2^F} \tag{8}$$

C	Number of all possible combinations of variants per domain D_x.
V	Number of all possible Variants per domain D_x.
F	Number of all EE functions per domain D_x.

The challenge of this optimization approach is that already a small number of functions in a domain create a multitude of combination c (cf. equation 8). For instance F= 5 leads to more than 4 billion combination c, for which cost calculation and optimum detection would have to be carried out.

$$C = \sum_{n=1}^{z} \frac{V!}{n! \times (V-n)!} \tag{9}$$

To reduce the set of combination and therefore to simplify the selection process of the C-ECU variants v, it is possible to define a maximum number z of C-ECUs feasible in a combination c (cf. equation (9)). This reduction is not inevitably necessary, but it reflects real specifications and corporate practice. By introducing z the result of the optimization approach might be the local optimum only, but not the global optimum.

The presented calculation to determine a cost optimal combination c in a domain has to be carried out for every existing domain in the EE-SA. The consolidation of the cost optimal combination for every domain Dx produces the optimized EE-SA.

6. Conclusion and outlook

The presented approach locates all EE functions including its related HW and SW in the C-ECU and S-ECUs domain-specifically. Thereby various C-ECU variants per domain are generated, from which the most cost-effective combination is being determined. The combination of cost-optimal domain specifications creates an optimized EE-SA. This optimized EE-SA can be applied across all model series of an OEM. Thus the OEM wide cost optimum for the EE-SA will be reached although it might not be coincide with the model series-specific cost optimums.

The presented optimization approach has positive effects on the EE development. It makes the existing complexity more transparent and controllable. Thus, it minimizes the DC and MC on a domain-specific level and therefore OEM wide.

The introduced status of the optimization approach includes several simplifications (cf. chapter 1-2). By revoking these simplifications, further potential for a future extension of the approach can be created:

- Optional equipment is not being considered in the optimization approach. With the additional consideration of original equipment and its factor take-rate the approach would even more detailed and closer to the corporate praxis.

- The developed approach presumes a set number of domains. An extended version of the approach which includes an optimized number of domains as the result would constitute another step towards a comprehensive model for the EE system optimization.
- To simplify the calculation of an optimal combination per domain, the presented optimization approach is to be developed in order to generate an optimization problem. Correspondingly, an appropriate optimization method is to be identified.

In summary, the presented optimization approach for function-partitioning in EE-SA creates a basis for the future implementation of further measures for the economic optimization of the product structure. In particular this includes the company wide development and implementation of modular construction sets, for which the EE-SA defines the structure. Identifying the correlation between EE-SA and modular construction set and developing an economic, technical and processual structure represents a potential research project.

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