Lessons Learned from Implementing Configuration Management within Electrical/Electronic Development of an Automotive OEM

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Abstract. In the past decade the automotive domain has encountered significant changes within its competitive environment. Automotive OEMs are forced to offer an increased number of variant models, to satisfy individual customer needs as well as constantly introduce innovative features within their products. Electrical/electronic systems play a major role enabling OEMs to address these needs. Development processes for electrical/electronic systems are moving into the focus of automotive companies. However current development approaches for these type of systems within automotive industry are only partially able to cope with the mentioned challenges and yield the necessary, high-quality systems. Thus automotive OEMs started to restructure their development approaches for electrical/electronic systems and introduce Systems Engineering.

This paper is illustrating lessons learned from implementing configuration management within electrical/electronic development as part of an major initiative at a German OEM to introduce Systems Engineering. The initiative is still on its way, therefore the lessons learned are only part of the truth. The paper will start by highlighting the current situation of the automotive industry and point out the future role of electrical/electronic systems for achieving competitive advantage. Based on this background the need for Systems Engineering, especially within electrical/electronic development will be discussed. Configuration management as a part of Systems Engineering processes will be described in general and in its application in an automotive environment. The specifics of configuration management within Electrical/electronic development of an automotive OEM will be highlighted and discussed. Afterwards the paper discusses lessons learned during conception and implementation of the configuration management building blocks into the OEMs organization. Key success factors for introducing configuration management as part of a Systems Engineering initiative into an existing process and organizational landscape are then derived from the lessons learned.

Abbreviations

OEM: Original Equipment Manufactures
E/E: Electric/Electronics or electrical/electronic
CM: Configuration Management
SUV: Sports Utility Vehicle
ECU: Electronic Controlling Unit
PDM: Product Data Management

Introduction

Competitive environment of automotive industry. In the past decade the automotive industry has faced and is still facing significant changes within its competitive environment. Mergers and acquisitions as well as joint ventures have changed the industry's structure, resulting in a reduced number of competitors, all being global players. The remaining automotive OEMs are in strong competition for customers. Achieving competitive advantage is now more important than ever before. Most automotive OEMs aim at achieving this competitive advantage by two levers:

- Increasing the number of product variants offered. This so called "Modelloffensive" (model offensive) aims at addressing market segments or niches not addressed before (i.e. SUVs, Roadster) and offering almost customer-individual cars. Every customer should have the chance to get the specific car, she or he really wants. If a customer doesn't get the specific car she or he really wants, she or he is less likely to actually buy a car and will possibly buy a car from a competitor. As illustrated in fig.1a BMW AG has steadily increased the number of variants within the last 30 years.
- Introducing innovative features with every new model. New features may cover a rather wide range, from safety-features (i.e. brake force display), driver-assisting features (i.e. active cruise control), comfort features (i.e. key memory) to communication/infotainment-features (i.e. multimedia-platforms). Every feature aims at differentiating an OEMs cars from the ones offered by a competitor. If a potential customer gets offered more features than a competitor offers, he is not only more likely to buy a car, but also he is willing to pay a higher price. As shown in fig.1 the number of optional features offered within a BMW model has increased to 250 within the last 30 years.

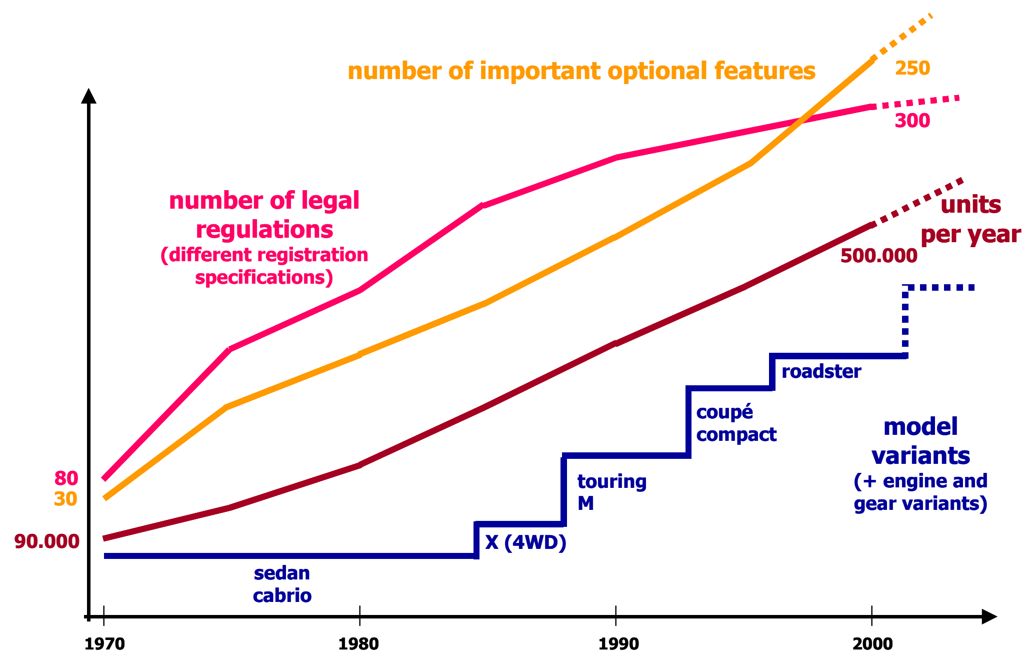

Figure 1. ***Evolution of number of models and functions offered indicate increasing complexity of electric/electronic development in automotive industry [Source: BMW AG and Frischkorn et al., 2000]***

Electrical/electronic systems as enabler for competitive advantage. In this competitive environment electrical/electronic systems are of increasing importance, due to innovations only based on technologies developed there. Currently about 80-90% of innovations within automobiles are based on electrical/electronic systems, the cost share of electrical/electronic systems has risen from 22% in 1997 to 32% in 2002 ([Dörr and König, 2000] and [VDI/VDE, 1999]).

Electrical/electronic systems within a car are typically realized as electronic controlling units (so called ECUs, which are basically microcomputers) and harness. State-of-the art cars in the premium segment (i.e. Mercedes S-Class, Audi A8, BMW 7 Series) today contain up to 70 ECUs[1], about 200 actuators and sensors, and more than 2 kilometers of cable. The ECUs themselves consist of rather diverse "parts" such as mechanical and electronic hardware, software, and application data. Functions implemented into ECUs communicate intensively via busses to provide higher level functions using data from sensors located all over the car (i.e. dynamic stability control uses speed data, traction data, momentum data, and acceleration data). Therefore a state-of-the-art on board architecture can be characterized as a highly complex network. In fig.2 the topology of the on board architecture for the current BMW 7 series is depicted (ECUs, harness, sensors, and actuators), to give an idea on its complexity.

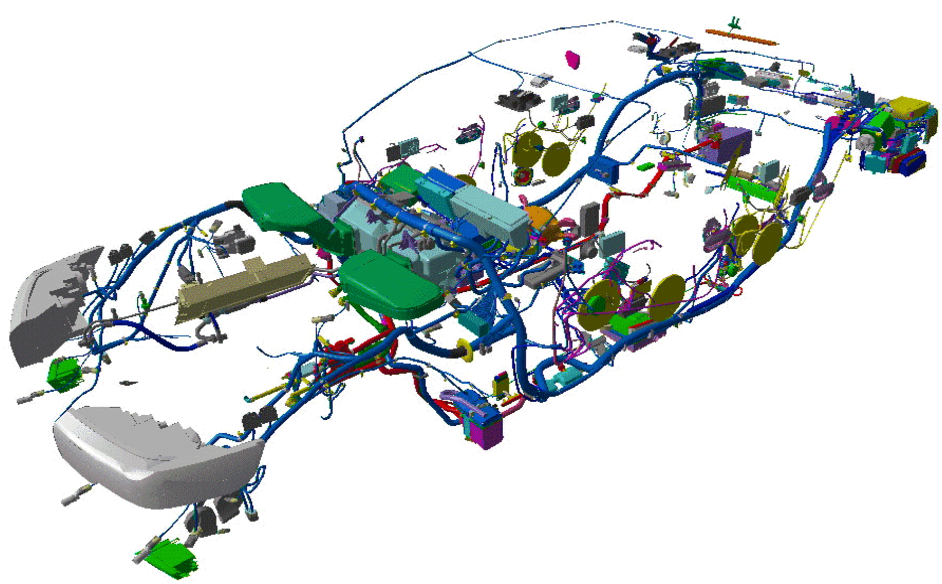

Figure 2. ***Harness within the new BMW 7 Series illustrating the networked character of state-of-the-art electric/electronic systems in automotive industry [Source: BMW AG]***

Besides its role as enabler for most of the today's innovative features in automobiles, electrical/electronic systems offers another interesting opportunity. The lifetime of a car model today usually is up to 10 to 15 years plus 5 years of development and 7 years of production. This totals 22 to 27 years from the initial product idea to refurbishment of the last unit. This is a rather

[1] Typically ECUs are distributed all over the car due to package, reliability, and performance constraints. In most cases a single ECU realizes one to four major functions. Therefore the number of ECUs is rather high compared with the overall number of major functions incorporated within a car.

long period measured in terms of electrical/electronic systems, where innovations cycles are typically about 15 to 18 months. Once being in service, a car therefore might need updates or even upgrades of its software features from time to time. There is a potential of customers willing to pay for software updates or upgrades. Thus there is an additional business case for automotive OEMs, which they won't ignore.

Electrical/Electronic development becomes key process. Based on the critical role of electrical/electronic systems its successful development will become a future key factor. Since product quality stems from high process quality, development processes for electrical/electronic systems move into the OEMs focus. This is accompanied by significant changes within the companies cultures, almost a clash of cultures, since they have been "steel-oriented" companies for a long time and now have to transform themselves into software- and system-oriented companies.

System design and system integration of an on board architecture are now critical processes, in order to be able to successfully integrate a high number of components mostly developed and supplied by first and second tier suppliers into a functioning and compatible on board system. The reasons why many of the components are developed by suppliers are rather simple. First, technologies necessary to develop the various components and features within an electric/electronic system are very heterogeneous and require very specific and diverse knowledge. It is not effective for an OEM to have necessary capabilities for all purposes in house. Second, the available resources of an OEM to develop the ever increasing number of model variants are limited. Thus, due to efficiency reasons OEMs deliberately decide to do the development work in house which focuses on key or lead models of the brand (i.e. innovative, new platforms, while derivatives would be done mostly by a first tier supplier). OEMs therefore focus on key aspects, like

- developing the lead model of a product line,
- functions of the product providing a unique selling proposition,
- innovations,
- system design and system integration,
- and supplier integration.

The need for Systems Engineering in electrical/electronic systems. In the media there is a growing awareness of an increasing number of breakdowns due to failure in electric/electronic systems, e.g. a number like 49,2% of car breakdowns in Germany are due to electric/electronic failures (see [SZ, 2003] and [Spiegel Online, 2003]). BMW GROUP statistics prove that despite growing complexity and growing production figures, the electric/electronic breakdown statistics are decreasing. Therefore high product quality is essential for an OEM. But high product quality stems also from a high quality development process. Electric/electronic systems are dominated by the characteristics of networked structures. Current development processes in use are still based on a component-oriented approach rather than on a system-oriented one. Besides, the rapidly increasing complexity of the electric/electronic systems is not only forcing OEMs to shift their current the development process for electric/electronic, but also to completely rethink these development processes, since they do not provide the high quality anymore, which is needed for competitive electric/electronic systems. Thus OEMs have to achieve excellent, system-oriented processes for the development of electric/electronic systems in order to gain competitive advantage. As a consequence BMW AG as one of the OEMs within the premium segment started to basically rethink its development processes within electrical/electronic systems and is about to introduce systems engineering as the future approach.

Specific needs of configuration management for electric/electronic systems within automotive industry

Systems engineering processes recognized as critical for restructuring. Currently there is no common understanding of what systems engineering is across various industry domains. Each domain interprets its own understanding of systems engineering and sometimes does not even call it systems engineering. Integrated product development, concurrent engineering, or simultaneous engineering are just a few approaches containing many systems engineering ideas, but not calling themselves systems engineering. However, looking at standard literature (see [INCOSE 2002], [Sage and Rouse 1999], [Martin 1997], [Clausing et al., 1999], [Daenzer and Huber, 1994], [EIA 632], [ISO 15288]) and many publications, one can get an idea about what the common core[2] of systems engineering is. This common core should also considered to be critical for a successful restructuring of the electric/electronic development processes.

Taking into account only the process aspect of systems engineering, the authors consider the following processes as key aspects within systems engineering:

- Core Processes
    - Requirements Engineering and Management
    - System Architecting
    - System Integration
    - Validation and Verification
- Basic Processes
    - Program and Project Management
    - Risk Management
    - Configuration Management

Configuration management is a basic process within systems engineering, because it rather provides the appropriate "process infrastructure" for the core processes to be successfully performed and does not directly contribute to design and development of the system. Besides project management configuration management is kind of a backbone[3] for the core processes and therefore has interfaces to all those. Being a process of a highly interlinked character makes it difficult to be embedded into the process landscape. Configuration management thus is a significant part of an systems engineering initiative.

Why not just use standard CM? Configuration management has a long tradition in many industries. Many publications, books and standards can be found on configuration management ([SEI 2000], [EIA 649], [MIL-HDBK-61], [Sage and Rouse, 1999]). Why is it, that an automotive OEM can not just take these standard approaches, which have been proven to be

[2] As common core of Systems Engineering the authors consider the building blocks of Systems Engineering, which are common to most of the standard literature. The following building blocks may be seen as the common core of Systems Engineering: SE Life Cycle, SE Principles, SE Organization and Human Aspects, SE Processes and SE Management, SE Methods and Tools, SE Work Products, Measurements. These aspects are only one way to define the common core. There may be other, more comprehensive ways.
[3] This backbone is often represented by an integrated IT solution for configuration management containing all the configuration data.

right many times and implement it into its organization? The type of configuration management published is mainly driven from domains outside the automotive domain and does only partially fit the specific electric/electronic needs within the automotive domain. These specific needs make a different view on configuration management necessary.

Basically there are four building blocks of configuration management within the automotive domain [Knippel et al. 2002]. The building blocks itself are not considered to be automotive specific, while their content is considered to be. The automotive specific aspects of each building block are discussed in the following paragraphs:

(1) Configuration management processes

   a. Baseline management (planning, establishing, auditing, and releasing baselines)

   b. Change management

   c. Deriving customer specific configurations

(2) Configuration management organization

(3) Product structure

(4) Configuration management IT infrastructure

The term “configuration” within electric/electronic systems incorporates three aspects: (1) the physical parts (software and hardware) to be built into the overall product, (2) the documentation of the physical parts (i.e. requirements, specification, design, test, operations), and (3) the tools to built the physical parts into the overall product (i.e. a tool for programming a software part into an ECU). Further more it is distinguished between a 100% and a 150% configuration. While a 150% configuration contains all possible variants of configuration (i.e. all available engine variants), a 100% configuration represents a single configuration variant (i.e. only a single engine variant). The automotive domain is characterized by very high numbers of possible configuration variants as illustrated in figure 3.

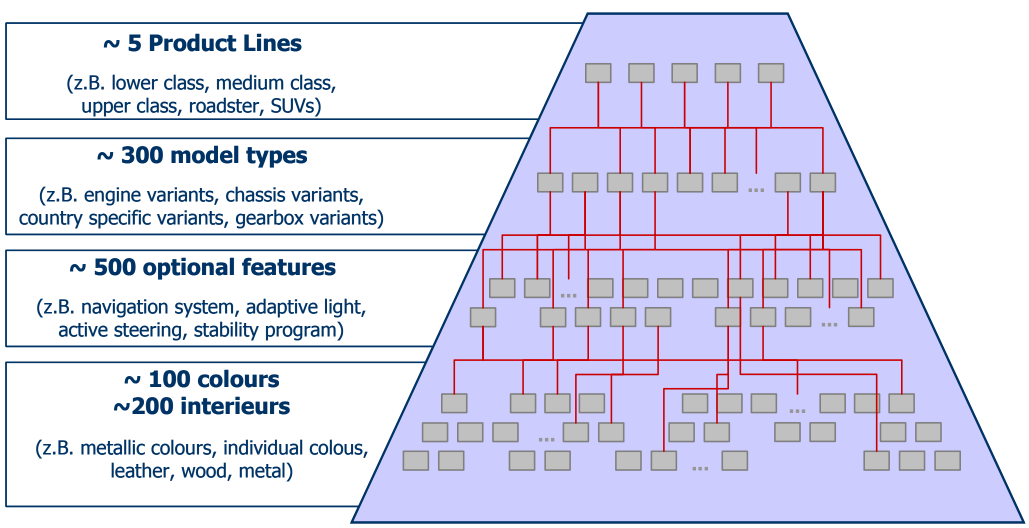

Figure 3. ***High number of possible configuration variants to be handled due to customer individual configurations [Schulz, 2002]***

The building block of configuration management processes for electric/electronic systems for automotive industry differentiates itself from standard configuration management through a number of aspects. The subprocess of baseline management has the challenge to cope with very heterogeneous contents, when baselining a design. This is due to the fact, that electric/electronic systems can not be described with a single "design language", but with very different "languages" from very different views. I.e. the functional design of an electric/electronic system typically contains the functions of a system and their interrelationships based on communication in terms of signals or messages transmitted via busses. The electric design of an electric/electronic system represents the physical architecture of the system in terms of harness, pinning, etc. Describing the functional design uses a very different language than describing the electric design. Figure 4 illustrates typical different views or layers of electric/electronic systems.

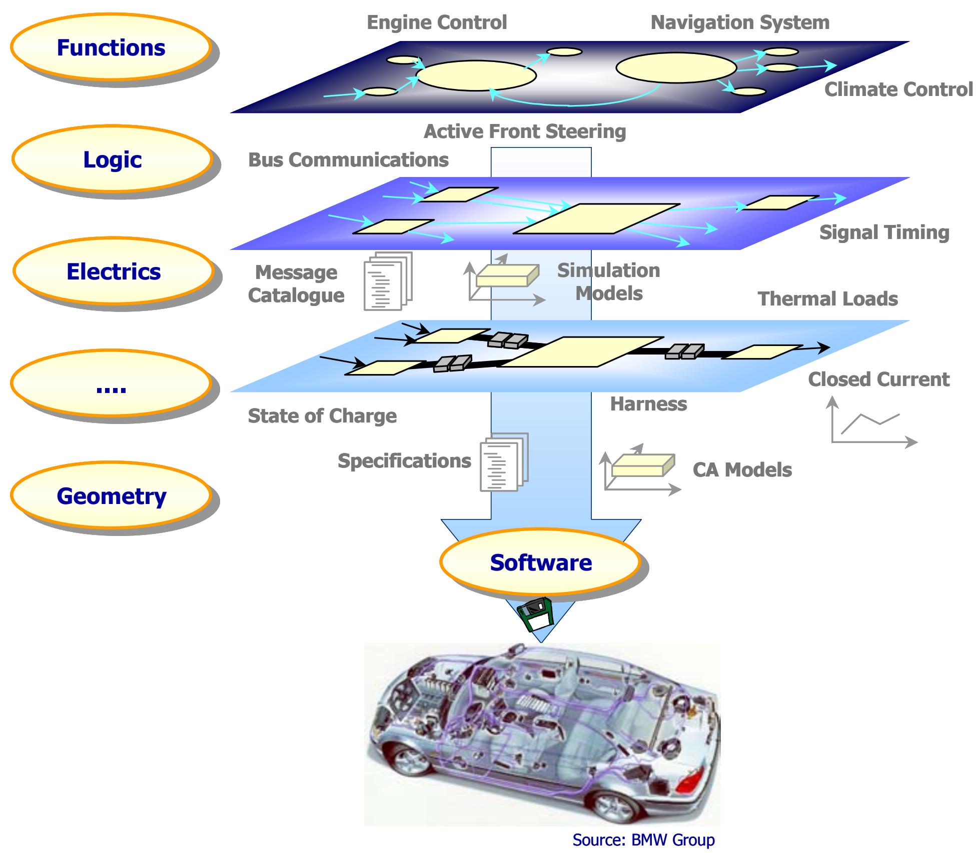

Figure 4. ***Different views on electric/electronic systems illustrating their heterogenous character [Fricke et al., 2000]***

Each view has its own process of creating and baselining (design) data. The data created for the different views have strong interrelationships among each other and also to data located outside the electric/electronic domain. Due to the specific expert tools used within each process, the (design) data is rather heterogenous. I.e. power management handles different design data than communication architecture (i.e. state of charge simulation models vs. topology models). Synchronizing these different processes and heterogenous (design) data applying common baselines is difficult, because of the strong interrelationships. That is in order to synchronize the design data, there has to be a certain sequence in which the data is freezed. Planning and establishing such an overall baseline consisting of separate baselines for each specific view is not provided by standard CM. The overall baseline is the basis for validating and verifying the configuration. The baseline has to incorporate the 150% configuration in order to inhibit all possible configuration variants. Due to the high number of configuration variants, it is impossible to validate and verify all variants. More over each specific view on the baseline needs a different methods for validation and verification. Handling these different validation and verification methods within an overall baseline is also not provided by standard CM.

The subprocess of change management has the challenge to cope with changes on very different configuration items and with unpredictable impacts. Handling software changes is different from handling hardware changes. Software may be changed very quickly and at usually very low cost. This typically imposes high changes rates, that is a high number of changes has to be handled effectively and efficiently and raises the need for a rapid change process in terms of deciding whether to make a software change or not. But electric/electronic systems are characterized by emergent properties, that is many properties and features are only visible on a system level. Changing a software subsystem or component may have an impact on a system level, which is not visible on a subsystem or component level. Assessing software changes in terms of their impact on the entire system is therefore very difficult. System models capturing all aspects of the system are not available, also because the system properties are very heterogenous. Besides software changes may have an impact on subsystems or components outside the boundaries of the electric/electronic system. Therefore an appropriate change management process has to apply appropriate methods to evaluate the impact of a change correctly and quickly.

The subprocess of deriving a customer specific configuration has the challenge of deriving a 100% configuration from a 150% configuration. Applying configuration rules[4] to the 150% configuration derives a 100% configuration. As already mentioned the automotive domain is characterized by very high numbers of possible configuration variants (see fig. 4). Handling such a high number of 100% configuration within a single 150% configuration requires the application and management of very complex configuration rules. These configuration rules have to define which configuration item variants comprise a valid configuration. Further more, it is very difficult to ensure the traceability from requirements to specifications to design models to prototypes to delivered configurations for such a high number of configuration variants.

The building block of configuration management organization for electric/electronic systems for automotive industry has no specific needs compared with standard configuration management. The same roles and boards as well as responsibilities of these organizational units may be applied.

The building block of product structure for electric/electronic systems for automotive industry again is very different from standard product structures known from other domains. As already mentioned electric/electronic systems are dominated by the characteristics of networked structures. Electric/electronic typically can be structured into functions communicating signals or messages via busses. Functions are realized as software modules running on different ECU hardware. State of the art upper class cars today contain up to several hundreds functions and

[4] Configuration rules describe the logic of deriving a 100% configuration from a 150% configuration. I.e a configuration rule might be “engine variant”. The values applicable to this rule might be “2.5 litre”, “3.0 litre”, and “4.0 litre”. The configuration item “engine” contains the different item variants “small engine”, “medium engine”, and “large engine”. Each item variant has a configuration attribute “valid for” containing all values of the rule for which the item variant will be configured within the configuration.

messages. Emergent properties of these networked structures like power management, electromagnetic compatibility, thermal management require different views on the networked structure, which can not be provided by a hierarchical approaches to structure the system. Creating a hierarchical bill of material (BOM) containing all ECUs and their components does therefore not represent the entire system and all its properties correctly.

Finally the building block of configuration management IT-systems for electric/electronic systems for automotive domain has to cope with some challenges not covered by standard configuration management IT-systems. The IT-system is typically used to administrate the product structure and its contents. Due to the networked character of the product structure of electric/electronic systems also the IT-system has to fulfill specific requirements and provide specific features. Standard PDM systems typically are focused on administrating and representing hierarchical BOMs and impose limitations on networked structures. The high number of specific tools necessary to model all the different views or aspects of a electric/electronic systems impose additional challenges on the IT-system, because for convenient handling of product data, all these tools have to have interfaces to the central repository containing the product structure. Figure 5 illustrates typical characteristics of an appropriate IT-system for configuration management of electric/electronic systems.

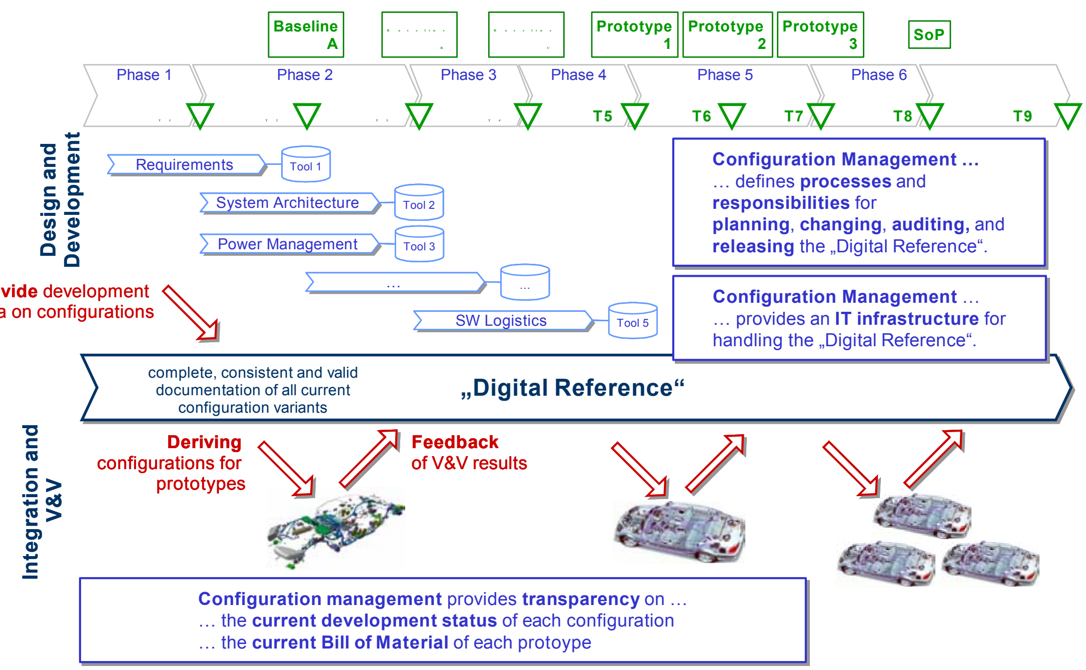

Figure 5. *Characteristics of an IT infrastructure handling electric/electronic systems*

Integrating CM into existing "process and organizational landscape". Since electric/electronic systems have only increased their importance for the automotive domain within the last 15 years, most automotive OEMs are still dominated by rather component oriented organizations than system-oriented organizations.

Embedding structures focusing on handling of systems and their emergent properties is difficult, because it requires a different approach. Design, architecture, integration, and verification on a system level is shifting away the focus from components as well as organizational units and processes on a component level. Software modules representing different functionalities are shifting away the focus from mechanical hardware components and require different tools, different processes, different people. Embedding these aspects into the existing landscape is a difficult process, because it is a clash of cultures.

The dynamics of the software world in terms of very short innovation cycles alter appropriate processes rather quickly. Existing processes do not incorporate the flexibility to cope with these rapidly changing requirements. Besides configuration management for electric/electronic systems has to not only to work together with processes on an electric/electronic system level a number of established processes on a enterprise level. Figure 6 illustrates some of the processes which have interfaces to a configuration management on electric/electronic system level.

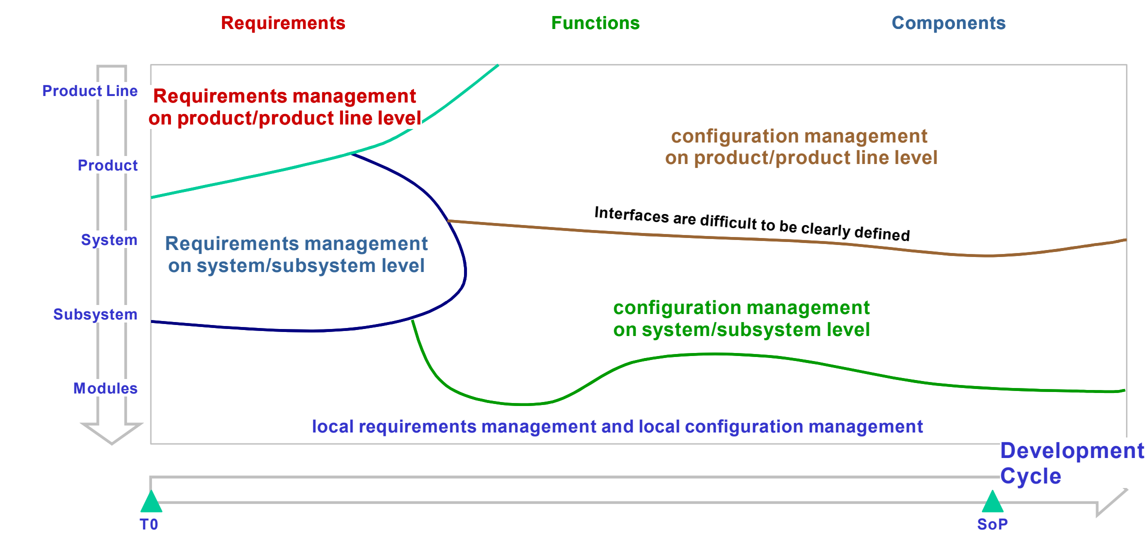

Figure 6. ***Embedding configuration management into an existing organizational landscape [Knippel et al., 2003]***

Lessons Learned during implementation

The project, where the lessons learned discussed in this paper come from, had a certain approach to define, validate, an implement the new CM approach into the existing organization. After an initial analysis phase, an overall concept for the future CM approach was defined based on deficiencies identified during the analysis. Critical areas of the future CM approach have been chosen for a first implementation and validation within selected product projects. This first implementation and validation will be called piloting in the following. The lessons learned discussed within this paper have been derived from piloting a new baseline management process within a single product project. Therefore not lessons learned may hold true for implementing a new CM approach within other product projects. However the authors selected the lessons learned from which they strongly believe that these hold true no matter what project or business environment one may have. The lessons learned are discussed in the following paragraphs.

(1) Any planning should incorporate three to six months of preparation or ramp-up time before actually starting to pilot any measures. This period is needed for building a common understanding between the various partners of new processes to be implemented and validated. More over this period is also needed for creating trust between the various

partners as a basis for an effective and efficient implementation. It is simply not possible to define some measures and then start right away.

(2) When looking for pilot partners, one should select those, who are open for new ideas and do not have to be convinced, that there is a need for systems engineering. That is the pilot partners should already have a certain level of problem awareness. Besides the pilot partner should be well acknowledged within the organization and willing to promote the results of the pilot approach.

(3) Selection and planning of potential measures should definitely take into account the upcoming milestones of your pilot partner, in order to understand what results he is really interested in and what time constraints limit the pilot planning; A limited number of measures to be implemented and validated, which are worked on intensively should be preferred to a high number of measures, which are worked on only superficially. Thus the selected measures focus on the few hot spots, where 80% of the benefits are realized and your pilot partner would have to work on anyway. No resources should be "wasted" on side aspects, where maybe 20% of the benefits may arise. Besides expectations of the pilot partners should be set carefully. Nothing should be promised which can't be achieved afterwards. Consider the KANO model of customer requirements: try to "overplease" your pilot partner and satisfy the unexpected excitement requirements.

(4) The communication towards the pilot partner is really important: Don't tell the pilot partner: "We want to achieve CMMI level x." The pilot partner will not be interested in any process maturity level, but in processes, which deliver better results (in terms of time, cost, and quality) than his existing processes. But the offer not only has to be the better process, but also the result of the better process. Therefore tell the pilot partner: "We want to provide a solution for your problem." Offering the pilot partner also the necessary resources to perform the new process in order to achieve a result, which he is responsible for, will get his interest. Providing those resources for the pilot partner will also create not only the capability but also the willingness to invest resources into the new approach.

(5) Working together with the pilot partner should incorporate taking part in the daily work environment of the pilot partner. Thus one is soon seen as a member of the team and greatly increases credibility and ensures acceptance of the measures to be implemented and validated. The resources needed by the pilot partner in terms of time needed by process experts (i.e. for analysis and discussion of measures) should be limited to a minimum. Those resources are a limiting factor, because process experts are typically very scarce and inquired by many people. Wearing out these resources is critical.

(6) When documenting the measures, an appropriate language should be used describing the measures by reusing existing and accepted terms. Any language used by standards (i.e. CMMI) often does not fit into the existing landscape or is merely understood by the pilot partners. One should not stick to any terms but translate inappropriate terms into "customer language". While documenting the measures implemented and validated for future reuse, a formal approach (i.e. using ARIS for process description) may be inappropriate. One should rather use the daily, operational language of the pilot partner. Often processes one wants to established are already informally existing, but named differently. One has to find these processes and use them as for anchors of the new structure.

Deriving key aspects of a successful approach for implementation

An appropriate approach for successful implementation. In order to actually learn from the lessons learned discussed, the authors recommend some aspects to be considered when planning an implementation.

(1) There is no standard approach for implementation. Planning an approach for implementation is very individual and specific depending on the situation and company environment. An appropriate approach has to be oriented at the company culture, which may vary from very formal to very informal. Each culture needs a totally different approach. In a formal culture formal documentation and management commitment is key. In an informal culture informal documentation and user acceptance is key. These two approach are totally different, since the latter is bottom-up while the first is top-down. An initial analysis, which creates the basis for planning an appropriate approach therefore should incorporate aspects of the company culture (i.e. “emotional aspects”) besides the mere identification and evaluation of the existing structures.

(2) There is no "first time right". In a complex business environment it is simply impossible to provide new structures first time right. It is rather a continuous “zig-zagging” of the work products/deliverables to be implemented between an application within various product programs and a reference of the work products/deliverables on an enterprise level (see fig. 8). A planning has to incorporate a stepwise evolution of the new structures, by constantly adapting the reference structures based on application experience in various product projects.

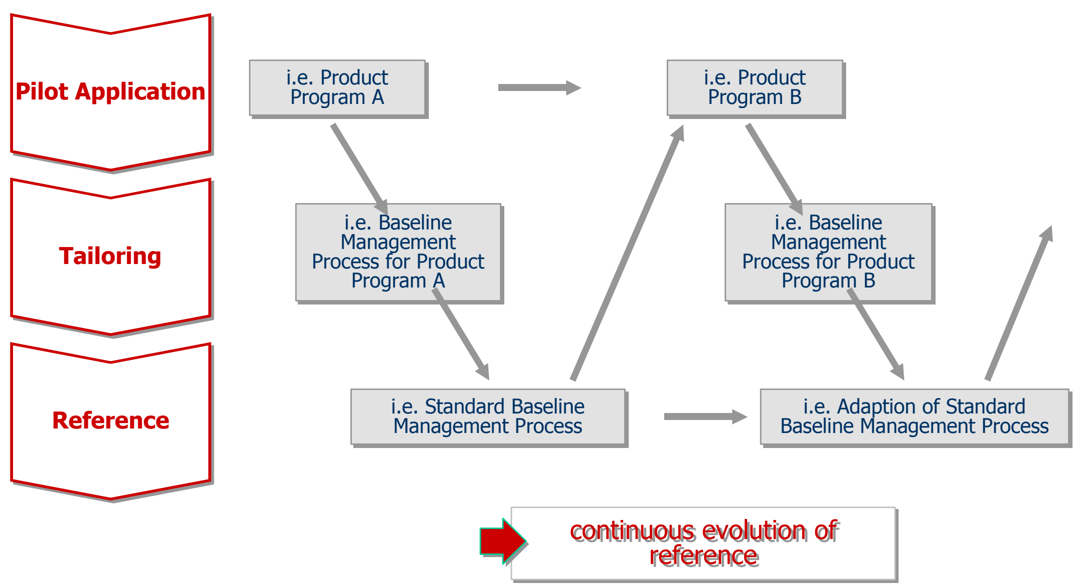

Figure 8. ***Zig-zagging a new process for continuous evolution of the reference process to be used as an enterprise standard [Knippel and Schulz, 2003]***

(3) An identification of the right stakeholders strongly depends from the work product/deliverable to be implemented. These stakeholder are not necessarily the ones of the initial problem making the work product/deliverable necessary. That is, there might be a gap between the problem and solution owners.

(4) Acceptance of a work product/deliverable to be implemented has to be achieved before anchoring it into the organization. There is a need for people promoting on an operational level: acceptance has to be achieved on the operational level, that is at the user level of a work product/deliverable (bottom-up acceptance). There is also a need for people promoting on a management level: commitment has to be achieved on a management level, that is at the owner level of a work product/deliverable (top-down commitment).

Summary and conclusion

This paper aimed at illustrating the current competitive situation of the automotive industry. Electrical/electronic systems has been highlighted as a key enabler for innovations and thus achieving competitive advantage. Due to the ever increasing complex nature of state-of-the-art electric/electronic systems, automotive companies have realized that there is a need for new and different development approaches, since the existing ones have trouble in coping with the challenges of electric/electronic systems. Systems Engineering and its core processes (i.e. requirements engineering, system architecting) seem to be an appropriate approach in developing electric/electronic systems. However such processes may be called, there are key to successful development of state-of-the-art electric/electronic systems and thus key enablers in achieving competitive advantage in automotive industry.

Configuration management as part of systems engineering plays an important role, because as a supporting process it provides the appropriate “infrastructure” for the systems engineering core processes to be successfully performed. But existing and standard approaches on configuration management do only partially fit the needs of automotive industry and in particular electric/electronic systems.

This paper has not described or prescribed any configuration management approach applicable for electric/electronic systems. This has not been the intention of the authors, because they believe, that there is no standard approach for electric/electronic CM working in every business environment. Any successful CM approach for electric/electronic systems has to be individually designed towards the specific company environment. However there are lessons learned, which are applicable in any business environment might help to make an initiative aiming at implementing systems engineering processes, in particular CM, into an existing organization successful. Critical aspects derived from these lessons learned, which are recommended to be considered during implementation may also help. Illustrating such lessons learned and discussing critical aspects has been the intention of the paper. The authors hope this contributes to the systems engineering body of knowledge and helps in implementing systems engineering approaches more successfully in commercial industries like the automotive industry.

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Biography

Erwin Knippel received a Diploma Degree in Electrical Engineering focussing on communication networks from Fachhochschule Rheinland Pfalz in Trier in 1988. He started his professional career at BMW AG as SW/HW engineer for ECUs within chassis development. In 1995 he switched to BMW M GmbH, a BMW GROUP subsidiary for sport cars and worked there as CA system administrator. In 1998 he switched to BMW Technik GmbH, another BMW GROUP subsidiary for study cars and became head of IT infrastructure as well as project leader for PDM introduction. In 2002 he moved back to BMW AG and took over as project leader configuration and change management within electrical/electronic development.

Armin Schulz received a Diploma Degree in Aerospace Engineering from Technische Universität München (TUM) in 1998 after studying at TUM und MIT. In 2002 he received a Ph.D. in Systems Engineering from TUM after completing his research on „Information Architectures within Product Development“. From 1998 until 2002 he worked with several industrial partners from automotive and aerospace industry on issues of information management and concurrent engineering environments. In 1997 he was co-founder of the German Chapter of INCOSE and has been member of its board from 2000 until 2003. In 2001 he became co-founder of 3D Systems Engineering, a consulting firm in the area of Systems Engineering, and has been working with 3DSE since then.