2004-21-0042

AUTomotive Open System ARchitecture - An Industry-Wide Initiative to Manage the Complexity of Emerging Automotive E/E-Architectures

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AUTOSAR Partnership

ABSTRACT

The current automotive electric/ electronic (E/E) architecture landscape is characterized by proprietary solutions, which seldom allow the exchange of applications between both automotive OEMs and their suppliers. It is apparent that on the basis of a continued exponential growth in functional scope, further proliferation of proprietary solutions will consume more and more resources and may become difficult to control.

AUTOSAR is a joint initiative of several major industry players and aims to prepare for the increase in functional scope.

This paper presents an overview over the development partnership as well as the technical concept and methodology. It concludes that introduction of an industry-wide standard of automotive E/E architecture is indeed vitally important and it is that, which will allow the industry players to concentrate on innovation rather than wasting effort when adapting existing components to different environments.

The AUTOSAR standard will thus help to secure market attractiveness and open new and different business opportunities for OEMs and their suppliers alike.

1. INTRODUCTION

Driven by the development of innovative vehicle applications, contemporary automotive E/E architecture has already reached a high level of networking to date. This trend is likely to continue on an even reinforced level, pushed by increasingly demanding legal and customer requirements, which are often conflicting:

- Legal enforcement – key items include environmental aspects and safety requirements
- Passenger convenience and service requirements from the comfort and entertainment functional domains
- Driver assistance and dynamic drive aspects – key items include detection and suppression of critical dynamic vehicle states and navigation in high-density traffic surroundings

Unlike past attempts where the automotive industry reacted in response to major technological advances[10], now a technological breakthrough is required in order to keep pace with these requirements.

Also, it has been recognized that this can hardly be handled by individual companies in isolation and rather constitutes an industry-wide challenge. Conclusively, leading OEMs and Tier 1 suppliers have jointly decided to establish an open standard for automotive E/E architecture, leading to the AUTOSAR partnership, which was formally launched in July 2003.

AUTOSAR serves as a basic infrastructure for the management of functions within both future applications and

[10] Recent examples include the transition from point-to-point serial communication to networked systems and the introduction of deterministic technologies.

standard software modules. The goals include the standardization of basic system functions and functional interfaces, the ability to integrate and transfer functions and to substantially improve software updates and upgrades over the vehicle lifetime.

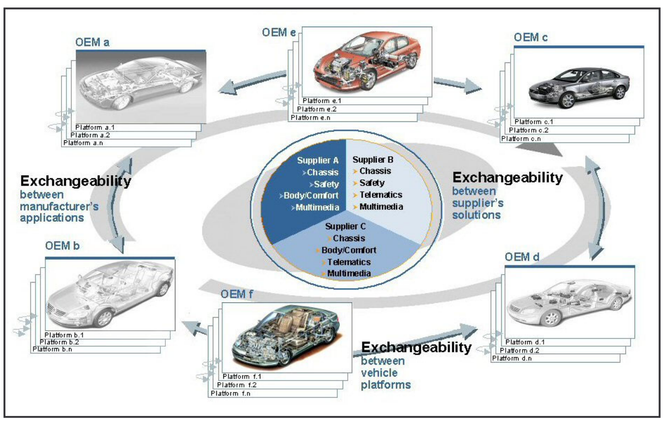
2. MOTIVATION AND OBJECTIVES

Motivations for standardization are:

- Management of E/E complexity associated with growth in functional scope
- Flexibility for product modification, upgrade and update
- Scalability of solutions within and across product lines
- Improved quality and reliability of E/E systems

Leading OEMs and Tier 1 suppliers, recognizing this to be an industry-wide challenge, decided to work together to create a basis for industry collaboration on basic functions and interfaces while enabling a standardized platform on which an efficient competition on innovative functions is enabled (see Figure 1).

Figure 1: Exchangeability of functions between OEM and suppliers



2.1 AUTOSAR PARTNERSHIP AND STANDARD

The development partnership **AUT**omotive **O**pen **S**ystem **AR**chitecture (**AUTOSAR**) has been formed in mid of 2003. This partnership aims to establish a standard that will serve as a platform upon which future vehicle applications will be implemented and will also serve to minimize the current barriers between functional domains (vehicle centric versus passenger centric). Its scope encompasses:

- Powertrain
- Chassis
- Safety (active and passive)
- Multimedia/Telematics
- Body/Comfort
- Man Machine Interface

Applied to these functional domains, primary objectives are:

- Consideration of availability and safety requirements
- Redundancy activation
- Scalability to different vehicle and platform variants
- Implementation and standardization of basic system functions as an OEM and supplier wide "Standard Core" solution (including e.g. bus technologies, operating systems, communication layer, HW abstraction layer, memory services, mode management, middleware/interfaces, standard library functions)
- Transferability of functions throughout network
- Integration of functional modules from multiple suppliers
- Maintainability throughout the whole "Product Life Cycle"
- Increased use of "Commercial off the shelf hardware"
- Software updates and upgrades over vehicle lifetime

Some principal classical challenges and the solutions suggested by AUTOSAR together with their implied benefits are listed in the table below.

Challenges	Solutions	Benefits
Non-competitive functions have to be adapted to OEM specific environments Tiny little innovations cannot be implemented at reasonable effort as provision of interfaces from other components requires a lot of effort Missing clear interfaces between basic software and code generated from models	**Standardized Interfaces**	Reduction/avoidance of interface proliferation within and across OEMs and suppliers. Eased implementation of HW-independent software functionality by using generic interface catalogues Simplifies the model based development and makes it possible of the use of standardized AUTOSAR code generation tools Reusability of modules cross-OEM Exchangeability of components from different suppliers
Effort wasted on layout and optimization of components which add no value recognized by the customer	**Basic Software Core**	Enhancement of software quality Concentration on functions with competitive value
Obsolescence of hardware (µC, circuits, ...) causes huge efforts in adapting existing software Extended needs for microcontroller performance (caused by new functions) cause need for upgrade, i.e. re-design effort	**Microcontroller Abstraction**	Part of the hardware can be exchanged without need for adaptation of higher software/ functions/ applications

Large effort when relocating functions between ECUs Large effort when re-using functions	**Runtime Environment**	Encapsulation of functions creates independence of communication technology Communication easier through standardized mechanisms Partitioning and relocatability of functions possible
Immature processes because of acting in ad-hoc mode/ missing traceabilty of functional requirements Lack of compatible tooling (supplier, OEM)	**Software Component Template** **Exchange Formats**	Improvement in specification (format and content) Opportunity for a seamless tool chain
OEM buys black-box and is not able to extend/integrate new functionality in an ECU (e.g. integration of tire guard functionality)	**Technical Integration of Software of Multiple Suppliers**	Eased process of integration of different software components allows optimization of hardware costs
Lack of guidelines for use/ buy of software components Unclear legal situation	**Conformance Test Process** **License Agreement**	Integration of 3rd party software components Common understanding between suppliers and OEMs

More generally, the change from proprietary solutions to a general standard will enable the following benefits:

- Increased reuse of software
- Increased design flexibility
- Clear design rules for integration
- Reduction of costs for software development and service in the long term
- OEM overlapping reuse of non-competitive software modules
- Focus on protected, innovative and competitive functions

Specific benefits for OEM:

- Functions of competitive nature can be developed separately
- Later sharing of innovations is accessible (additional ROI)
- Standardized certification

Specific benefits for supplier:

- Reduction of version proliferation
- Development sharing among suppliers
- Increase of efficiency in functional development
- New business models
- Preparation for upcoming increase in software volume

Specific benefits for tool provider:

- Common interfaces with development processes
- Seamless, manageable, task optimized (time dependent) tool landscape

Specific benefits for new market entrant:

- Transparent and defined interfaces enable new business models
- Clear contractual task allocation and outsourcing of Software-Implementation accessible

Main strategic targets to accomplish the project objectives are modularity, configurability and transferability of software modules and the standardization of their interfaces.

3. TECHNICAL CONCEPT

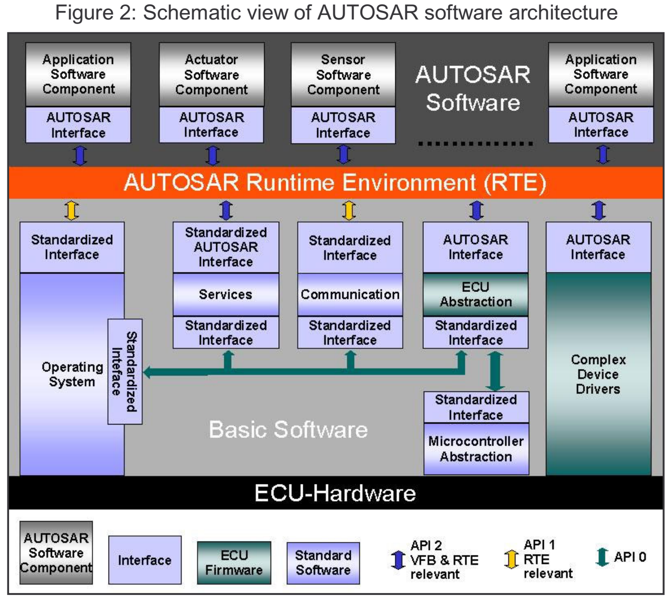
3.0 OVERVIEW

To achieve the technical goals modularity, scalability, transferability and re-usability of functions AUTOSAR will provide a common software infrastructure for automotive systems of all vehicle domains based on standardized interfaces. The AUTOSAR standard encompasses:

- Standardization of different APIs to separate the AUTOSAR software layers
- Encapsulation of functional software-components
- Definition of the data types of the software-components
- Identification of basic software modules of the software infrastructure and standardize their interfaces

AUTOSAR will enable optimization of the entire vehicle network as well as the configuration process (e.g. partitioning and resource usage) and if required, allow for local optimization to meet the runtime requirements of specific devices and hardware constraints.

Figure 2: Schematic view of AUTOSAR software architecture



3.1 AUTOSAR SOFTWARE ARCHITECTURE

Figure 2 shows a schematic view of AUTOSAR software layers; its main elements are described below.

3.1.1 BASIC SOFTWARE

Basic Software is the standardized software layer, which provides services (for access to input/output, memory, communication, system) to the AUTOSAR Software components and is necessary to run the functional part of the software. It does not fulfill any functional job itself. The Basic Software contains standardized and ECU specific components. The standardized Basic Software includes:

- **Basic Services**, such as
  - Operating system services. The standardization of automotive operating systems is not regarded as an AUTOSAR goal but existing standards and products such as OSEK, VxWorks, Windows CE and other RTOS for automotive and their derivatives will be taken into consideration and used in AUTOSAR.
  - Vehicle network communication and management services (e.g. CAN/LIN, FlexRay, MOST)
  - Memory services (NVRAM management)
  - Diagnosis Services (including KWP2000 interface and error memory)
  - ECU state management
- **Microcontroller Abstraction**
  This is also referred to as Standard Peripheral Controller Abstraction (SPAL) and directly accesses the µC internal peripherals and memory mapped µC external devices whilst decoupling higher software layers from the hardware. It comprises:
  - Microcontroller Drivers
  - Memory Drivers
  - Communication and I/O Drivers
  - I/O Drivers

ECU specific components are:

- **ECU Abstraction**
  It interfaces to the Microcontroller Abstraction. It also contains drivers for external devices and offers an API for access to peripherals and devices regardless of their location (µC internal/external) and their connection to the µC (port pins, type of interface). Its primary purpose is to make higher software layers independent of the ECU hardware layout through:
  - Onboard Device Abstraction
  - Memory Hardware Abstraction
  - Communication Hardware Abstraction
  - I/O Hardware Abstraction
- **Complex Drivers**
  These implement complex sensor evaluation and actuator control with direct access to the µC using specific interrupts and/or complex µC peripherals (like PCP, TPU), e.g. for injection control, electric valve control or incremental position detection. A Complex Driver fulfills the special functional and timing requirements for handling complex sensors and actuators.

3.1.2 AUTOSAR RUNTIME ENVIRONMENT

At system design level (i.e., when drafting a logical view of the entire system irrespective of hardware) the AUTOSAR runtime environment (RTE) is abstracted to a Virtual Function Bus (VFB) that acts as a communication center for inter- and intra-ECU information exchange. All communications run through the AUTOSAR VFB. AUTOSAR VFB provides a communication abstraction to Software-components attached to it by providing the same interface and services whether inter-ECU communication channels are used (such as CAN, LIN, FlexRay, MOST, ...) or communication is intra-ECU. As the communication requirements of the software components running on top of the RTE are application dependent, the RTE needs to be tailored to these communication requirements. It is therefore very likely, that the RTE will be fully generated to provide required communication services while still being resource-efficient. Thus, the resulting RTE will likely differ between one ECU and another.

3.1.3 AUTOSAR SOFTWARE (APPLICATION LAYER)

The AUTOSAR Software consists of Software-Components that encapsulate automotive functionality or pieces of it (i.e. interfaces, resource requirements, timing, etc). Its specification covers requirements and attributes that are prerequisites to run the Software-Component in an AUTOSAR compliant environment. At the architectural level any communication between Software-Components and elements of any other layer is routed through the AUTOSAR runtime environment. The AUTOSAR interfaces assure the connectivity of software elements surrounding the AUTOSAR runtime environment. Standardization of the interfaces for AUTOSAR Software-Components, operating systems and basic software is a central element to support scalability and transferability of functions across electronic control units of different vehicle platforms.

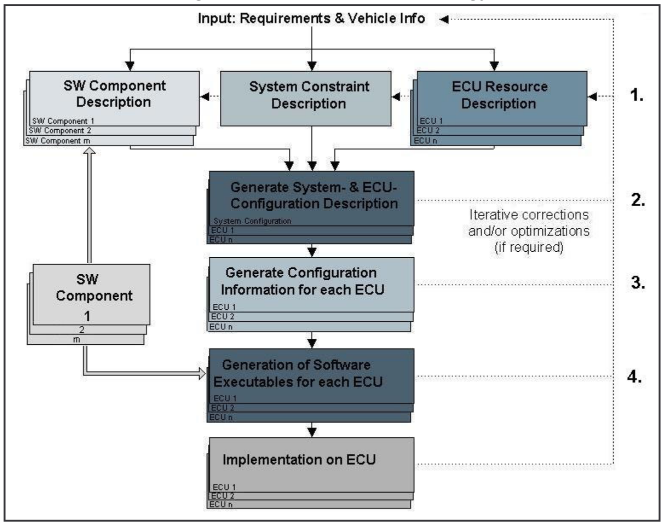
- Scalability of functions will ensure the adaptability of common software modules to different vehicle platforms to limit proliferation of software with similar functionality.
- Transferability of functions will optimize the use of resources available throughout a vehicle's electronic architecture.

The AUTOSAR interface is not a piece of software separated from any particular software component but rather an integral part of the latter.

3.2 SYSTEM DESIGN – SUPPORT BY AUTOSAR

The AUTOSAR methodology describes the process leading from system design to implementation, which is illustrated in Figure 3. The presented separation does also correspond to typical responsibility boundaries of the stakeholders and experts collaborating to design and deploy such systems.

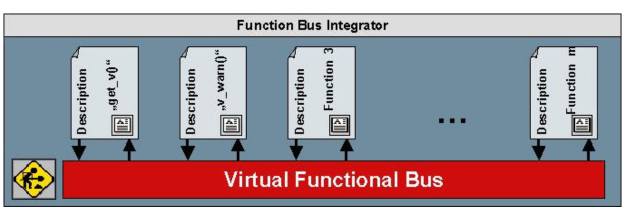
Figure 3: AUTOSAR Methodology



The basis of this process is a set of three main descriptions that are deducted from existing vehicle information and the set of requirements to satisfy customer needs:

- **Software Components**
  The logical functions that are visible to the customer are described irrespective of the actual, physical hardware, i.e. available ECU and network topology.
  Also, the software component descriptions logically represent the software components irrespective of their implementation details, e.g. the function bodies adhering to the code syntax of a chosen programming language.
  Each software component requires an own, individual and unambiguous description.
  To support this logical view and in order to accomplish the objective of transferable functions the concept of the Virtual Functional Bus (VFB) is introduced (see Figure 4).

Figure 4: VFB View of the System (speed warning example)[11]



The Software Component Description includes:

- Interfaces, behavior (repetition rate)
- Direct hardware interfaces (I/O)
- Requirements on run-time performance (memory, computing power, throughput, timing/latency)
- …

- **System Constraints**
  This comprises system wide information, such as the network infrastructure, as well as distribution of the Software components to the available ECU.
  The System Constraints Description includes:

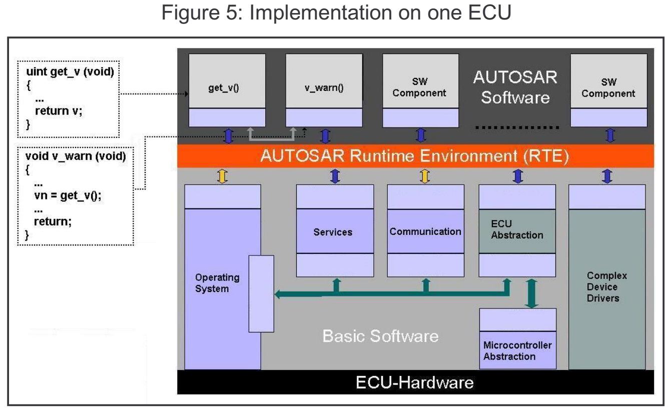
- Bus systems, protocols, communication matrix and attributes (e.g. data rates, timing/ latency, …)
- Function clustering
- Function deployment (distribution to ECU)
- …

- **ECU Resources**
  For each ECU in the system a description has to be provided that represents the physical and electronic attributes of that ECU.
  The ECU Resources Description includes:

- Sensors and actuators
- Hardware interfaces
- HW attributes (memory, processor, computing power, …)
- Connections and bandwidth, etc.
- …

Obviously, the concluding step of this process is the download of the software on the actual hardware. To illustrate the transferability of functions (as a central AUTOSAR objective) two scenarios based around a speed warning function (as an example) are shown below:

Figure 5: Implementation on one ECU



In the above example both dependent functions are implemented on the same ECU. This reduces the overhead of the AUTOSAR-RTE to a minimum.

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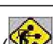
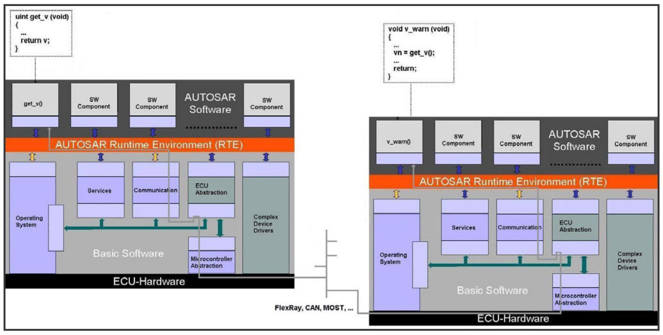
[11] The work symbol () denotes a supporting tool, which in this case can also be utilized to check completeness, integrity and correctness of the software component descriptions including interfaces ('Virtual Integration').

The alternative configuration can be on integrating the dependent functions across two, separated ECU. Apparently, information flow requires routing through an appropriate bus system. This is illustrated in Figure 6.

Figure 6: Implementation on two ECU

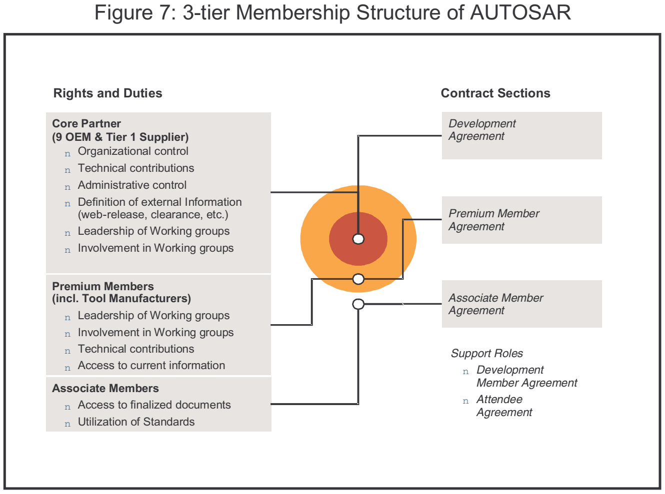


Note, that in both cases the application layer code is identical (simple function call, presented in C syntax as an example). The functions on the application layer themselves have no knowledge about the physical location of their counterparts and interface to the RTE exclusively. The latter takes care of appropriate routing of all information flow.

4. AUTOSAR INITIATIVE

The AUTOSAR partners have been in the process of partnership preparations since October 2002 and the partnership agreement was signed in July 2003. The partnership has adopted a three-tier membership structure that has been proven in similar initiatives. Each tier of the partnership has specific rights and duties that are regulated in appropriate agreements (see Figure 7).

Figure 7: 3-tier Membership Structure of AUTOSAR



Core partners have organizational and administrative control, make technical contributions and determine the information to be distributed externally. The core partners are BMW Group, Bosch, Continental, DaimlerChrysler, Ford Motor Company, PSA Peugeot Citroën, Siemens VDO, Toyota Motor Corporation, and Volkswagen.

Premium members participate in and can lead working groups, make technical contributions and have access to current information.

Associate members may use the standards and have access to finalized documents before release to public. The partnership will also welcome third parties to join as Development members or Attendees, both of whose participation is free of charge.

Development Member participates in and co-operates with the Partnership in one or more Working Groups in accordance with further instructions and guidelines from the Partnership.

Attendee contributes to the establishment of close connections between corporate research and development work undertaken by the Partnership and commercially independent, non-corporate research and development work represented by the Attendee and the institution which he represents.

5. PROJECT STRUCTURE

The AUTOSAR development partnership is organized in the following bodies, which are formed by the core partners:

5.1 EXECUTIVE BOARD (EB)

The Executive Board (EB) is established to focus on the following areas:

- Defines the overall strategy and roadmap of the Partnership
- The EB meets on a regular basis either in person or via telephone conference

5.2 STEERING COMMITTEE (SC)

The Steering Committee (SC) is established to focus on the following areas:

- Manages the admission of members, public relations and contractual issues
- Coordinates the day-to-day non-technical operation of the AUTOSAR partnership
- The SC meets on a regular basis either in person or via telephone conference.

5.3 PROJECT LEADER TEAM (PL-TEAM)

The Project Leader Team (PL Team) is established to focus on the following areas:

- Coordinates the day-to-day technical operation of the AUTOSAR partnership
- The PL Team coordinates the technical WGs (working groups) that shall report to it
- The PL Team meets on a regular basis either in person or via telephone conference

5.4 WORKING GROUPS (WG)

Working Groups (WG) are established to focus on the following areas:

- Responsible for the technical development work
- Several work groups exist for the various technical areas
- Specification of an AUTOSAR Runtime Environment to provide inter- and intra-ECU communication across all nodes of a vehicle network
- Definition of standardized interfaces across the different vehicle domains
- Definition of requirements and analysis of existing solutions in the area of basic software modules and automotive operating systems
- Definition of data exchange formats for describing necessary elements of a vehicle's E/E system architecture

5.5 ADMINISTRATOR

The Administrator is established to focus on the following areas:

- Supports the AUTOSAR partnership in various organizational and administrative issues
- Serves as the primary contact for membership applications
- Maintains the partnership server and homepage
- Collects membership fees, handles purchases of the partnership

5.6 SPOKESPERSON

The Spokesperson is established to focus on the following areas:

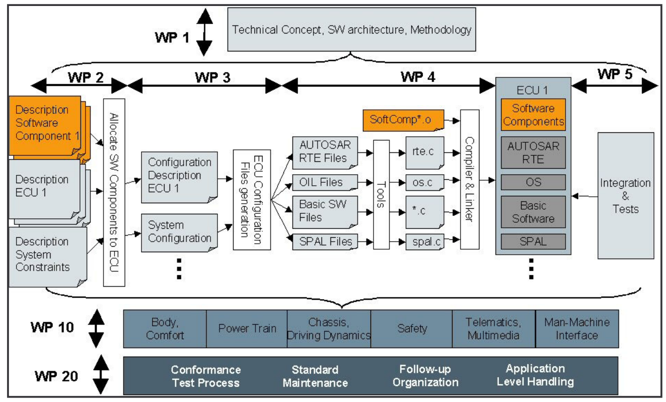
- Is authorized to communicate with journalists, analysts and media on behalf of the partnership
- Is the authorized representative of the partnership
- Is a member of the Steering Committee, serves for one year and is supported by a Deputy Spokesperson

6. WORK PACKAGES

The development of the AUTOSAR standard is organized into a number of technical work packages, each of which is further subdivided (e.g. WP 1.1.1, 4.2.2.1, etc.). Any individual work package is the responsibility of the associated working group.

Figure 8 illustrates the scope of the individual work packages with respect to the overall context. It can be seen that work packages 2, 3 and 4 follow the presented methodology approach, concentrating on the individual steps with clearly identified interconnections. Each work package is further specified below.

Figure 8: Scope of work packages



6.1 WP 1 THE AUTOSAR CONCEPT

WP 1 is concentrating on principal and conceptual issues, such as:

- Specification of the mechanisms and interfaces of the virtual functional bus
- Specification of AUTOSAR requirements on the basic software modules
- Review of effects caused by dependable systems (high availability, safety-relevant) on the AUTOSAR concept

6.2 WP 2 AUTOSAR-INPUTFORMATS FOR SYSTEM GENERATION

Subject of WP 2 is the system generation (i.e. the first step in the AUTOSAR methodology). This includes specification of the descriptions format and contents (i.e. templates for software components, system constraints and ECU descriptions) and the associated set of tools.

6.3 WP 3 AUTOSAR ECU CONFIGURATION

The AUTOSAR ECU-configuration is the process delivering configuration files of the particular run time environment modules (AUTOSAR run time Environment & Basic-Software) for each specific ECU from the information (used resources, implemented software components and communication relations) that are generated by the AUTOSAR system generator.

6.4 WP 4 ECU SOFTWAREGENERATION

WP 4 is defining the process of generating software executables out of the ECU configuration files. This includes specification/standardization of the input formats, tools to create and visualize the input formats, algorithms for and generation of the AUTOSAR RTE as well as qualification and implementation of "existing" Basic-Software.

6.5 WP 5 TEST- AND INTEGRATION PROCESS

Subjects of WP 5 are system integration and test, considering both product and process oriented approaches. This will make usage of a prototype implementation supporting representative applications, which will be developed alongside definition of the standard.

6.6 WP 10 DATA DESCRIPTION

The content of WP 10 is the formulation of unified functional interfaces of all vehicle domains:

- Body/comfort
- Power train
- Chassis/driver dynamics
- Safety
- Telematics/multimedia
- Man-machine interface

With respect to this, unified functions with clear semantics of the interfaces are published in function catalogues of the AUTOSAR-partnership (like the MOST function catalogues). All specified functions have to satisfy the AUTOSAR- Software-Component-Template.

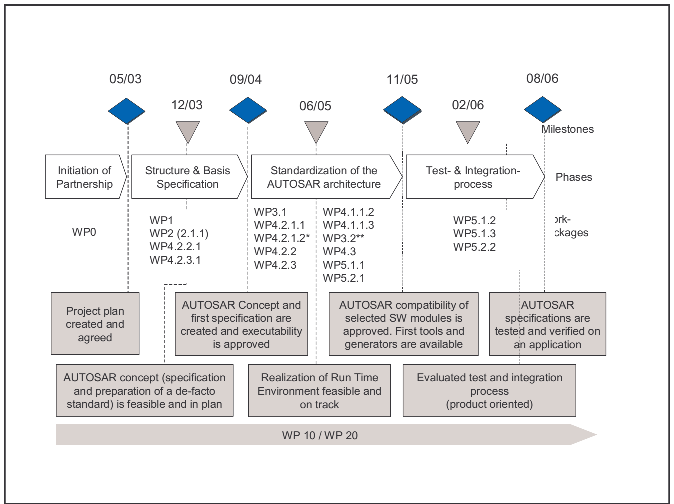
6.7 WP 20 ENABLING OF AUTOSAR EXPLOITATION

Subject to WP 20 is the definition of the conformance test and licensing procedures, version control management and continuous maintenance of the AUTOSAR standard including the timeframe beyond the current development project.

7. PROJECT SCHEDULE

The admission process has been formally initiated on 25th September 2003.

Figure 9: Project Schedule



The project structure is divided into four sections. In the startup phase the partnership was initiated by setting up a detailed work plan and project management. Phase 2 is determined by the definition of interface specification and AUTOSAR concept harmonization. In Phase 3 focus is set on the standardization of the software components. The phase of testing and integration will finalize the development phase of the AUTOSAR standard.

8. CONCLUSION

The introduction of the AUTOSAR standard will place the future of E/E-development in automotive industry on a commonly accepted and stable basis. This will be the key element in order to cope with the functional and legal requirements in next generation vehicle architectures. In addition the increasing uptake of software solutions is placed on a reliable design basis allowing for functional (re-) integration and concentration on the development of real new and novel functionalities.

The standardization in AUTOSAR is mandatory in the automotive industry in order to secure market attractiveness.

REFERENCES

1. http://www.autosar.org

CONTACT

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

API: Application Programming Interface

AUTOSAR: Automotive Open Systems Architecture

CDD: Complex Device Driver

RTE: Runtime Environment

SPAL: Standard Peripheral Controller Abstraction

VFB: Virtual Functional Bus