CONFRONTING COMPLEXITY

Arriving at the Need for a Design-to-Manufacturing and Design-for-Service Flow in Automotive Electronic / Electrical Engineering

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ABSTRACT

In this paper, the problem of complexity that confronts electronic and electrical (EE) design engineers in the automotive industry today will be discussed. The forces driving growing complexity in designs will be identified, including the pace of technological advancement, increasing legislative safety and environmental mandates, and escalating consumer demand. The consequences of escalating complexity for automotive EE designs and total manufacturer product cost will be analyzed. Areas needing improvement in current practices will be suggested and a suite of tools focused on the design-to-build-and-service flow will be described.

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1. INTRODUCTION

Engineers designing electronic/electrical (EE) systems for today's transportation systems must feel at times as if they were wearing concrete boots. One foot is weighed down by complexity resulting from advances in capability and functionality due to increasing integration of technological innovations by manufacturers. This weight is added to by government-mandated environmental and safety features, such as passenger restraints and emission controls. The other foot drags under the load of complexity introduced by consumer choice: the demand for options, customizations, and personalization resulting in an ever-widening array of model variations.

It is true that engineers have to go through a series of steps to create an automobile of satisfactory quality, reliability and cost – but now they are being presented with a choice between straining from side to side lifting heavy, uncomfortable boots, or striding briskly along a straight line in running shoes.

Growth in automotive EE applications and broadening consumer choice are together creating a serious challenge for design teams. With competing demands attempting to steer their development efforts, and vying for attention and scarce resources, design problems are becoming exceedingly complex and difficult to resolve.

Complexity is the common thread among the problems designers must overcome while striving to reach parallel but competing goals. Manufacturers need to effectively manage complexity in order to offer products that build brand recognition through advanced features, functionality and reliability while satisfying regulatory mandates and managing lifetime costs through warranty. Savvy consumers want cars with selectable options tailored to individual preference, reliable mechanical and safety features, and good value in terms of total cost of ownership.

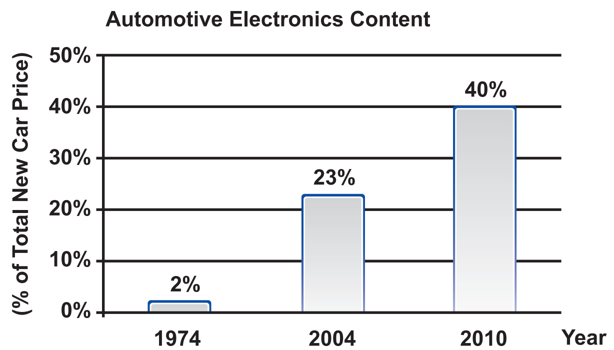
The challenge for designers is apparent. In the face of unrelenting technological advances and stagnant R&D budgets, they must enable manufacturers to build distinctive brands, differentiate their products in a highly competitive marketplace, and satisfy consumer demand while gaining control over escalating total product costs. Accomplishing this objective will require a new approach to automotive EE design methodology and efficient, flexible and powerful tools that facilitate a comprehensive process flow *from design through manufacturing and warranty.*

2. CAREENING COMPLEXITY

Manufacturers must simultaneously contend with several key constraints affecting the design process: explosive growth of electronic systems, decreasing development cycle times, increasing rate of vehicle launches, reduced development budgets, and escalating warranty costs.

A significant force in the growth of complexity in automobiles has been the rapid increase of mechatronic (electro-mechanical) sub-systems included in the EE architecture of modern vehicles. The Institute of Electrical and Electronics Engineers (IEEE) describes mechatronics as "the synergetic integration of mechanical engineering with electronic and intelligent computer control in the design and manufacture of industrial products and processes." Examples of areas in automotive EE design in automobiles today that involve mechatronics include systems such as suspension and stability control, transmission and drive train control, emission and thermal management controls, climate control systems, and braking and steering systems to name but a few. Combining sensors, actuators, electronic control units (ECU) and the network that links them, the design of mechatronic systems bridges across multiple engineering disciplines, requires resolution of complex problems interwoven among hardware, software, control, mechanical and electrical engineering domains.

Over the last 30 years the number of mechatronic systems in the typical automobile has grown from an average of four to more than 20. High-end luxury cars may incorporate as many as 80 such systems integrated in sophisticated networks. Correspondingly, the cost of these systems reached 23% of total vehicle cost in 2004 and is expected to reach 40% by 2010.



Source: IC Insights & Infineon, Emerging IC Markets - 2005 Edition

Figure 1: Unabated Automotive Electronics Growth

Design cycles have been dramatically shrinking from 48 months in 1985 to 24 months in 2004 and are expected to plummet to 12 months in 2010, meaning that there is significant shortening of the amount of time engineers have to complete, test and verify new systems.

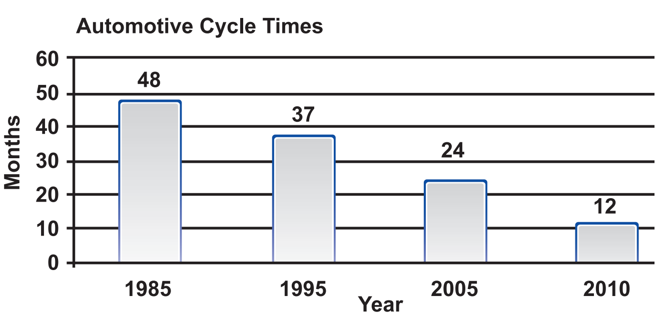


Figure 2: Decreasing New Model Cycle Times

Furthermore, the swelling of functions and feature sets that can be offered in cars today, along with the increasing technological savvy of the buying public, have resulted in marketing efforts and consumer demand that are responsible for a steadily rising tide of vehicle launches. For example, in China's rapidly growing economy, rising consumer demand may result in a radically different set of product feature sets from those in European and North American markets. The effect on manufacturers is a significant broadening of the platform options and variants (OV) they must be able to offer consumers on a global scale. The complexity of model configurations driven by market forces (such as brand competition and consumer choice) is key to understanding the comprehensive challenges manufacturers face in EE design today.

Lastly, but certainly not least, implementation of advanced EE designs has been accompanied by an undesirable growth in related warranty costs. In 2003, manufacturers of automobiles spent $12 billion on warranty expenses – *nearly half of the total warranty expense incurred by all manufacturers in North America for that year.*

Company	2003 Claims	% of Sales
All U.S. Mfgs.*	$23.6B	1.9%
Cummins Inc	$172M	2.7%
General Motors	$4.4B	3.0%
Ford Motor Co	$3.5B	2.5%
Navistar Int'l	$189M	2.7%
Paccar Inc	$159M	2.1%
Deere & Co	$334M	2.3%
Dana	$58M	0.7%
Textron	$151M	1.6%
Caterpillar Inc	$484M	2.3%

*All North American Manufacturers including auto.
Source: Warranty Week 04/2004

Figure 3: Warranty Cost for Automotive Manufacturers is a significant portion of all North American warranty costs

Comments from manufacturers suggest that as much as half of warranty costs may be related to problems in embedded software functions used by manufacturers to differentiate their products. The trend points toward warranty costs that are beginning to outstrip development costs.

The simultaneous growth of these pressures is overwhelming automotive EE design teams globally. The problems they face are further aggravated by static development budgets that have been consistently declining as a percentage of total sales. In the face of these serious constraints, today's automotive electronics ***designers are being asked to do more with less***.

3. HOW IS INDUSTRY RESPONDING?

Automotive manufacturers and suppliers are making efforts to respond to design problems driven by effects of complexity. To be successful, they must:

- Manage the steady growth of on-board electronics
- Achieve more integrated functionality
- Meet higher demands for quality and reliability
- Reduce and control warranty costs

In the automotive industry today, there is no common approach to EE design. Few companies or divisions have shared processes and there is no emergent consensus guiding makers of design tools toward development of a comprehensive tool set. As a result, most electronic design automation (EDA) companies have yet to address the challenges associated with system-level modeling and platform-level system integration.

Designing and optimizing vehicle electronic and electrical systems is still largely a process characterized by proprietary tools and methods, often manifested as in-house customized spreadsheet analysis tools that are esoteric to the needs and goals of a particular design engineer or process segment. A largely manual approach, analysis and optimization are typically performed individually on isolated subsystem ECUs.

The multiplexing of modern automotive EE designs that occurs between subsystem ECUs creates even more challenges and requires resolving communication problems and interaction conflicts. In the face of growing EE system complexity, it becomes increasingly difficult to optimize designs.

Original equipment manufacturers (OEMs) have responded to complexity-driven problems by attempting to limit the steady growth of on-board electronics with restricted option sets. They have also been trying to adopt more desired functionality through efforts at greater automation in design processes and embedded design analysis.

There is also a strong current of support for standards development that continues in the tradition of the OSEK standard.[1] Emerging standards such as AUTOSAR (Automotive Open System Architecture) are in development, and the existing IEEE standard VHDL-AMS language is currently in use for modeling and simulation of designs. Other important standards in the process of adoption includes STEP - AP212, 210, 233 to name a few.

Current efforts are not keeping up with problems and costs driven by surging complexity. The technological and market forces in play require a comprehensive, whole-process approach that keeps the entire landscape of design in view – from the earliest system concept to the service and warranty stage of any product life cycle.

4. A ROADMAP FOR NAVIGATING THE COMPLEXITY CHALLENGE

Growing electronic implementation, shrinking cycle times, stagnant development budgets, broadening

[1] "Offene Systeme und deren Schnittstellen für die Elektronik im Kraftfahrzeug" (Open systems and the corresponding interfaces for automotive electronics). An established standard for real-time operating systems for electronic control units (ECU). This particular standard originated in Germany, and included BMW, Bosch, Daimler-Benz, Opel, Siemens, VW, and the IIIT of the University of Karlsruhe.

consumer demand, and the need to control product costs through service and warranty aggregate as a formidable collective force for efficiency and utility in design practice.

The demand for efficiency and utility translates to a need for vendor-independent tools and accepted industry standards that will facilitate reuse of components and embedded functionality. Manufacturers simply can no longer afford the enormous cost of one-off component and system design, relying chiefly on physical prototyping and testing, or the limitations of proprietary methods, components, subsystems or tools.

In order for manufacturers to use embedded software functionality to cost-effectively differentiate their products in the market place, they must be able to simulate, test and verify component and system models at every step of the design-to-manufacturing process according to deterministic, correct-by-construction methodologies. Adoption of tools and methodologies based on standardized languages (such as VHDL-AMS) and industry-standard application programming interfaces (API), such as the emerging AUTOSAR standard, will support establishment of libraries (book-shelving) of proven component models and embedded software functions that represent modular, scalable, transferable, and reusable functionality that is vendor- and hardware-independent.

To respond to the shortening of platform cycle times, OEMs must be able to decrease development time through enhanced reusability of designs and subsystems.

In addition to book-shelving of component designs and embedded software, designers need tools that support automation of network design and verification that can quickly, easily and accurately integrate the diverse components, subsystems, buses, and topologies into a comprehensive platform network design.

Designers can also save critical development time by getting the design right from the start, employing a "correct-by-construction and design rule" design methodology from the earliest stages of the design process. This means modeling of system functionality and behavior – according to design rules expressed in corporate intellectual property (IP) – before coding at every design step. Correct-by-construction design mandates downstream enforcement of specifications used early in design through top-down, deterministic constraints that enhance predictability.

Importantly, as the number of systems incorporated in automotive platforms increase, manufacturers must have effective means of managing the growing volume of design data, including thorough change documentation. The specifications and rules defined in corporate IP, the selectable components and subsystems, and approved physical platform models must be made available in standard formats that provide accessibility of design information across the enterprise.

To contend with the rapid growth of automotive electronic content, manufacturers must manage complexity, employ more automation in design processes, and achieve faster, more reliable system integration and component design.

Managing complexity requires a coherent, accessible method of collecting, storing and retrieving design information to support modeling, analysis, and decision making. It also must support documentation of platforms according to the defined option sets manufacturers offer to consumers and the model variants that manifest consumer choices and other market conditions.

Automation is needed in two critical areas of the design flow. Greater automation of design and verification of hardware, software and mechatronics systems is needed, going beyond mere ECU design automation and focusing on interactions between hardware, software and the network connecting the platform components and systems. Improved automation is also needed in the design of electrical, electronic and embedded software components, requiring a stable and reliable software development environment for modeling, simulation, verification and testing of software interfaced to actual hardware.

With designs complete for the system, mechatronic subsystems, components, and the network connecting them, designers need tools that assist them with automated integration of electrical distribution systems tailored to the specific model variations that result from option choices. Tools designed for this purpose require a physical understanding of vehicle MCAD (mechanical computer-aided design) models so that locations for placement of devices and pathways for cables and wires can be determined. By combining this physical knowledge of the platform with understanding of specific device connectivity and system interconnect requirements, synthesis of the wiring harness can be automated. Ideally, a truly holistic approach would not only start with physical knowledge of the vehicle topology, but would also finish by sending data containing placement information back to the MCAD models to inform factory processes.

Tools that quickly and efficiently automate the integration of complex system architecture, hardware and software components, network topologies and composite vehicle wiring harnesses will help manufacturers manage complexity and accelerate the design-to manufacturing flow.

Successfully doing more with less depends on the ability to support the increase in the number of vehicle launches while improving quality, reliability and controlling costs.

Tools and technologies for network design automation, composite wiring synthesis, generation of customized graphical views, and integration of design data with manufacturing processes will bring efficiency across many stages of the flow. More efficient use and management of integrated design and manufacturing data can make engineers more productive, reduce design time, and improve communication across the enterprise. A data flow that enables the access to key design data can increase the efficiency of the design process by the use of concurrent engineering.

Effectively controlling warranty expense requires greater predictability, reliability and quality in the overall system design.

The sophistication of modern automotive designs has surpassed the capability of physical prototyping for development, verification and testing of systems and components in a timely and cost-effective manner. OEMs need a solution that provides robust system simulation and virtual prototyping, emphasizing system-level modeling, analysis and design over integration, validation and testing. Adoption of design flows informed by “correct-by-construction and design rules” methodology, as well as automation of mechatronics and embedded software design, will improve reliability and predictability of platform EE designs. Effective collection, archiving and management of design data is also a powerful decision-support tool. Specifications, company IP, reusable components and verified system models can aid engineers as they analyze design alternatives and confront important design decisions. All of these improvements to design flows have enormous potential to improve the quality and reliability of products delivered to market, enhancing consumer satisfaction and reducing warranty costs.

The rapid growth of embedded software demands a robust embedded software development environment and proven embedded components.

The use of embedded software to differentiate automotive products is increasing dramatically. A static, real-time operating system (RTOS) that supports the OSEK standard is essential for mission-critical functionality in automobiles. In the ideal embedded software development environment, support for common bus topologies (CAN, LIN, etc.)[2] and software prototyping is essential. In addition to standard development tools, the environment must include a library of embedded software components required to build specific system functions (for example, powertrain, telematics, body electronics and passenger comfort, safety and emissions).

5. MENTOR GRAPHICS STRATEGY: COMPREHENSIVE SOLUTIONS FOR AUTOMOTIVE DESIGN

The many-faceted problems of complexity in automotive EE design today affect the entire industry, but in particular they confront OEMs and their primary suppliers (Tier 1 suppliers). They are simultaneously contending with the need for solutions to these growing problems. This industry-wide struggle to manage complexity and costs, accompanied by emergent efforts at defining design standards, shows that the industry is ready for a full electronic design solution that brings improved quality, efficiency and functionality to the entire design-to-manufacture flow, while enhancing management of costs across the product life cycle, particularly in the crucial warranty stage.

The need is apparent for a comprehensive, full-flow solution that addresses the problems automotive manufacturers are facing in today's marketplace. Mentor Graphics Corporation, a leading provider of EDA solutions worldwide, is taking this challenge very seriously. In a bold initiative, Mentor is providing automotive designers with solutions that respond to the demanding problems of modern EE design.

Put simply, Mentor Graphics can't transform concrete boots into running shoes, but can help engineers stop lumbering from side-to-side under cumbersome loads and start taking confident strides along a straighter, more determinate line.

Mentor Graphics has traditionally served the transportation industry by supporting component design, especially among Tier 2 suppliers, through EDA tools targeting FPGAs, PCBs, and embedded software functions. Recognizing the escalating need for processes, methodologies and tools to effectively manage the complexities of designing modern automotive EE systems across the entire product life cycle from design to warranty, Mentor has assembled a powerful array of products to help automotive manufacturers meet the explosive challenges of complex automotive electronic and electrical design.

Mentor Graphics is specifically addressing the needs of the automotive industry with the following solutions:

Volcano™ Communication Technology

Network design automation tools, multiplex bus system analysis (CAN, LIN, MOST, etc.), deterministic approach to "correct-by-construction" in-vehicle software, network test and validation.

SystemVision™

System-level design and analysis of mixed-signal models bridging multiple domains (mechanical, electrical, controls); conceptual, functional, architectural, and component level abstractions; virtual integration of mechatronic system components with full VHDL-AMS, SPICE, and C language support; interface with MATLAB/Simulink.

Capital Harness Systems (CHS)

Electrical distribution system design, simulation and analysis, design data and change management,

[2] CAN – Controller Area Network; LIN – Local Interconnect Network

engineering and manufacturing analysis and support, enterprise integration (bridges for MCAD, PDM, etc.)

Embedded Solutions

High-level, model-driven architecture design with 100% code generation, system-level simulation and prototyping tools, and debugging and profiling tools, all integrated in a single Eclipse-based IDE offering full interoperability, together with software IP components including real-time operating systems, a complete middleware offering, and a full OSEK solution provided under a royalty-free business model.

The powerful tools included in these comprehensive product suites provide designers with solutions to challenges in automotive EE design from conceptual design through embedded functionality.

6. VOLCANO AUTOMOTIVE NETWORKING TOOLS

The effect of design complexity on the network is a rapidly growing communications burden. A steadily rising number of signals traveling across multiple subsystems and increasingly complex network topologies present a challenge that no longer can be effectively addressed by designing with a vaguely defined approximation of "designed-in headroom" required to accommodate fluctuating network traffic.

OEMs and Tier 1 suppliers are producing multiple ECU subsystems that are in some respects mini-networks themselves for functions such as body electronics, power train, etc. Incorporating these subsystems in the overall vehicle design can and does often result in significant problems, such as unpredictable behavior including information loss, unwanted delays and intermittent errors that compromise functionality and performance.

Rapidly escalating complexity overwhelms the network with signal traffic, causing unwanted interaction between functions. As the network expands to accommodate an increasing number of ECUs and subsystems, testing effectiveness is compromised by the sheer number of possible combinations of signal interactions. Flooded with signal broadcasts, the communication load may require more powerful and costly microcontrollers and increased memory capacity due to an increasing number of interrupts and frames received and transmitted.

To overcome these problems, automotive OEMs today need a more top-down, deterministic network design and verification process that allows engineers to anticipate networking requirements and execute designs that are based on management of known signal processing needs.

Mentor Graphics' Volcano Communication Technology (VCT) is a comprehensive suite of networking and data communications solutions that provide powerful support to designers of in-vehicle networking systems. The Volcano product suite includes:

Volcano Network Architect

High level requirement capturing early in the design, automatically map signals to frames for better bandwidth utilization. HW-independent, signal-based API abstracting.

Volcano In-Vehicle Software

Signals-oriented API simplifies application development by abstracting the communication from the application; predictable behavior reduces testing.

Volcano Test and Validation

Monitor and display multiple network signals in one tool. Advanced emulation capabilities for simulating user-defined functionality.

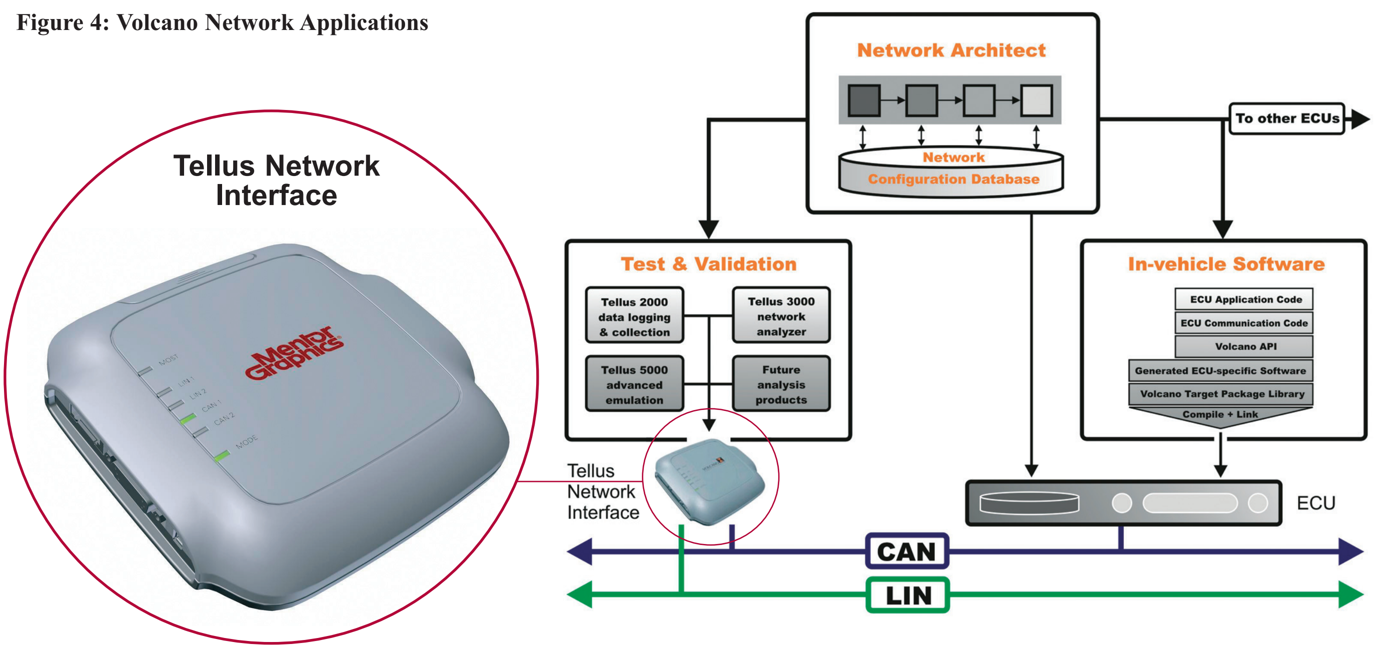
6.1. Volcano Network Architect (VNA) uses mathematical modeling to analyze signal processing requirements according to the maximum age of signal allowed between publishers and consumers of signals. It automatically packs the frames and optimizes the communication matrix through analysis of worst-case, subsystem-to-subsystem communication scenarios. This analysis moves design effort away from the current back-end-loaded process (design definition, limited simulation, integration and test) that yields high warranty exposure, to a front-loaded, deterministic process (modeling analysis and decision, correct-by-construction at every design stage, confident integration and validation) that enhances quality and reliability, reducing warranty and recall expense.

VNA calculates utilized network bandwidth by evaluating network requirements and available topology and determining whether all signals traveling through the network are "schedulable" – that they will arrive at the proper time. Error indications guide engineers in making adjustments to the network design to eliminate scheduling problems. Conversely, if all signals are schedulable, engineers can experiment with design alternatives or changes (such as removing an unneeded gateway or ECU, using a lower speed bus, less memory, or a less expensive microprocessor) to simplify the design or reduce costs without compromising network bandwidth or system functionality. Virtually all of the factors that affect performance or drive costs in automotive network design can be analyzed and intelligently revised in VNA. Volcano also generates report and configuration files for export to other tools.

6.2. Volcano In-Vehicle Software is embedded software IP for use in automotive electronic system ECUs. It provides comprehensive "target packages" of embedded code for communication with CAN and LIN buses through a signal-based API. Interfacing the communication and the application via this API simplifies the application development and enables quick communication configuration changes, saving weeks in development time.

The packages contain the compiler and switch settings which define the object code to enable network communication for specific microcontrollers. Volcano software is ISO 9000 certified characterized by high quality and a very low memory footprint, helping to further reduce costs. Volcano target

Figure 4: Volcano Network Applications



packages support all leading microcontrollers for automotive CAN and LIN bus networking. In-vehicle software facilitates the implementation of network optimizations accomplished in VNA.

6.3. Volcano Test and Validation tools. The Volcano solution suite also includes the Tellus network interface. Tellus provides a network-independent interface to physical networks for test and validation. The interface includes two CAN ports, two LIN ports and one MOST[3] port. In its simplest form, Tellus is a firmware reconfigurable product that can be connected to a network to log data. For example, it could be installed in a prototype car to log data while executing tests exercising a number of subsystems. The logged data can be analyzed to examine the cause of conflicts or errors.

The Volcano Tellus interface can be used for more sophisticated network analysis based on requirements defined in the network architecture, detecting errant frames and flagging those for follow up by the designer. In its most advanced form, the Tellus interface can emulate a known good network, providing a means for merging the virtual and physical prototyping worlds to accommodate legacy components found in the designs of most car platforms (a considerable percentage of every vehicle design contains design elements and components from some earlier platform version). Through emulation, the network model that has been virtually prototyped and verified in VNA can be observed interacting with the properties of accessible physical networks that do not actually exist in the Volcano environment. Multiple bus interfaces together with high time resolution make Tellus ideal for analysis of gateway behavior.

Volcano technology makes design of complex automotive networks easy and predictable. Network communication is guaranteed, dramatically reducing verification effort. Costly changes are avoided and warranty costs due to networking problems or failures are virtually eliminated.

[3] MOST (Media Oriented Systems Transport) is a high-speed optical multimedia network used in automotive infotainment applications

7. SYSTEMVISION

SystemVision is a design and analysis tool suite comprised of three integrated tools:

Schematic Capture Program

Front end design application that provides easy graphical design with full access to a model library.

Mixed Signal Simulator

Multi-language simulation core that supports VHDL-AMS, SPICE, and C model simulation.

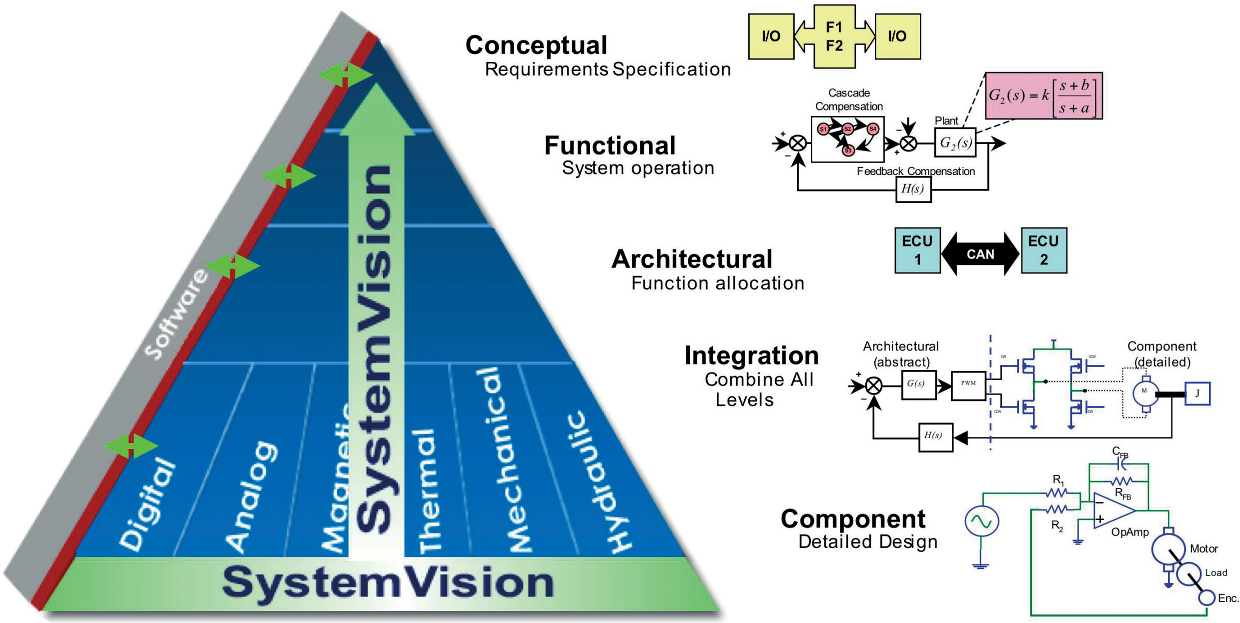
Waveform Viewer

Post-simulation processor analysis of results in time and/or frequency domains; displays proper units (is "type aware") for a given discipline, as well as time-aligned mixed analog/digital waveforms.

Spanning conceptual, functional, architectural, and component levels of system modeling and analysis, SystemVision helps designers contend with the complexities of mechatronic system design. Using SystemVision, designers can define requirements and specifications of the design, explore system functionality and make system partitioning decisions. Design details can be verified with virtual integration into the original executable specification.

The ability to effectively simulate system and component models is critical to dealing with the complexity challenge. Simulation uses sophisticated algorithms to analyze model behaviors in terms of time or signal frequencies, making it possible to virtually test the system to reduce risk of unintended behaviors or outright failures. Since the overall system model is composed of individual component models

Figure 5: SystemVision Design Solution



connected together, getting the component models right is essential to successful system prototyping.

SystemVision provides an intuitive and easy to use prototyping environment that supports multiple levels of system abstraction across multiple engineering technology domains. Analog, digital and mixed-signal circuits can be abstracted and analyzed along with mechanical, electrical, thermal, and hydraulic systems, continuous and sample-data control systems (and many other engineering effects) in an environment that allows for the fluent, multi-level integration required for true electronic system-level design and analysis.

Using SystemVision, engineers can quickly and easily create and analyze designs that include all levels of abstraction from math-based behavior down to circuit implementations. SystemVision can be used as a numeric analysis engine, providing a very high level of modeling fidelity that helps pinpoint problems through waveform display of signals, amplitudes and timing when a problem (such as a blown fuse) occurs.

In this environment, high-level behavioral models can be combined with lower-level device and effect models, allowing designers to rapidly examine the effect of design tradeoffs.

Employing the powerful IEEE standard VHDL-AMS modeling language, SystemVision also supports SPICE and C modeling languages to provide exceptional modeling flexibility. The VHDL-AMS standard enables and supports reuse of models from multiple engineering domains. SystemVision includes special modeling blocks that enable linking of schematics to simulations in a Simulink system. In addition, SystemVision works with The MathWorks' Real-Time Workshop, enabling generation of C code for the entire Simulink model that is targeted for a system simulation with SystemVision or the real-time target.

The SystemVision core includes a single-kernel engine that ensures accurate mixed-signal simulation results. The simulator core accepts multi-language system and circuit descriptions and generates viewable waveforms in a technology-aware format. Block diagrams and

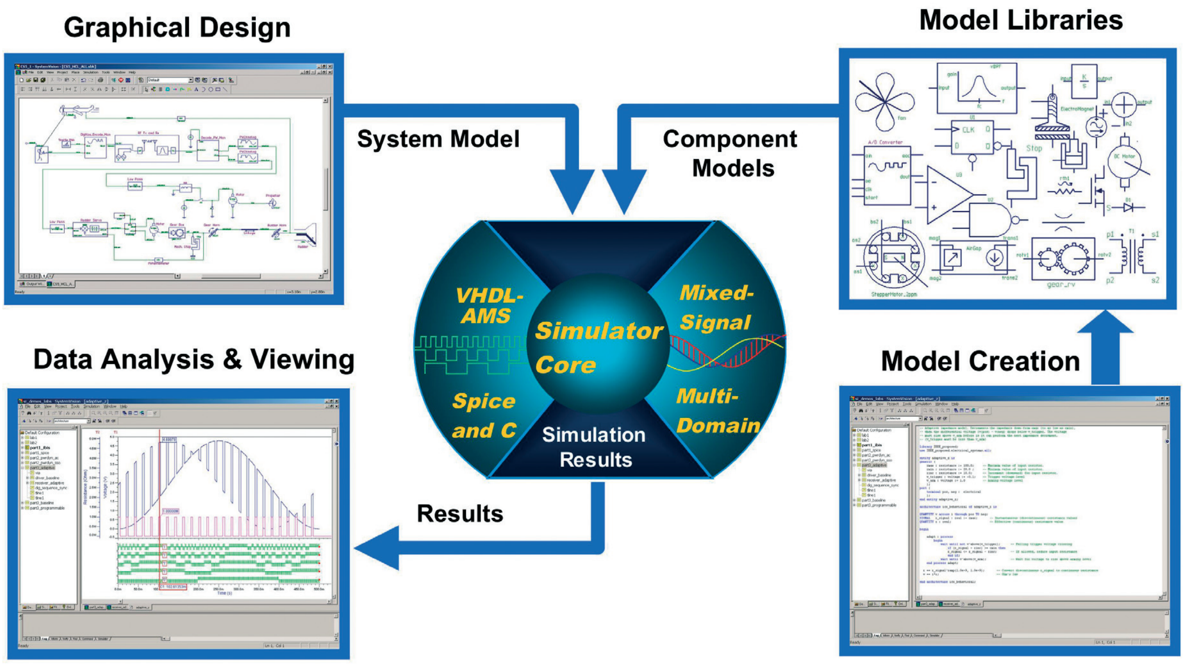


Figure 6: The SystemVision core includes a single-kernel engine, which ensures accurate mixed-signal simulation results. This core accepts multi-language system/circuit descriptions, and generates viewable waveforms in a "technology aware" format.

transfer function blocks assist designers with high-level concept verification. Hierarchical schematics and circuit elements assist them in verifying electronic and mechatronic system designs.

SystemVision users are provided access to a resource center that contains tutorials, examples, and case studies as well as an open-source VHDL-AMS model library. The library contains device and effect models spanning several technologies, such as electrical, mixed-signal, mechanical, fluidic, magnetic, thermal, transfer block function, and z-domain.

8. CHS - INTEGRATION & INTERCONNECTION

Nowhere do the concrete boots of complexity weigh more heavily than in the integration and interconnection of electrical systems and design of their associated wire harnesses. Electrical design is a truly high impact task that has long term implications on the cost and performance of the vehicle. The reason for this is simple: system packaging and variation within the electrical system from varients and options can dramatically increase copper content and cost. In fact, the wire harnesses installed in a modern car account for several percent of the total weight and cost of the vehicle. Add in the space demands of bulky wire harnesses plus the warranty / reputation impact of electrical failures, and the importance of the electrical domain becomes all too clear.

At this point it is appropriate to ask: "Why isn't the complexity of vehicle wiring decreasing as functions are moved to in-vehicle software and silicon processors, and signals passed around via networks?" In fact for the reasons noted above designers try very hard to minimize wiring content. But the massive growth in vehicle functions and hence signal count, plus the need to provide substantial power and ground services to devices such as lamps, motors and actuators, means that at best designers have only been able to hold wiring content approximately level for the past decade. A modern car still contains literally kilometers of wiring.

Within this landscape the challenge of complexity arises in some special ways. These include:

Cross-domain complexity. Electrical design is a truly electromechanical (or mechatronic) activity, ranging from signal connectivity capture to physical design-for-manufacture. Hence electrical design tools must be useful for both electrical and mechanical designers. For example, it might be necessary to capture and act on the fact that a low voltage sensor signal must be routed within the vehicle to avoid electromagnetically noisy zones; and the wire-end terminals carrying the signal must be gold plated to minimize contact resistance. Software functionality, on-screen dialogs and data representations must all recognize this cross-domain demand.

Integration complexity. Because of these cross-domain characteristics electrical design tools must be well integrated with other design and enterprise software. Data must be leveraged and shared with maximum efficiency and minimum risk of synchronization errors. This integration challenge is especially acute as organizations require concurrent engineering in order to reduce time to market, and global design libraries and processes in order to minimize development costs. Most obviously the electrical tools must be integrated with mechanical (MCAD) tools. But integration with other corporate systems such as PDM, ERP, user security and configuration control tools will very often also be needed.

Cross-organization complexity. Electrical design data crosses several organization boundaries, for example between an OEM and a tier 1 or tier 2 harness supplier. Common data standards or process flows barely exist today. So electrical design software must be flexible enough to support multiple flows, and powerful enough to accomplish organization transition tasks such as part number and graphical style translation.

Functionality complexity. To provide business value design tools must automate complex, time consuming or error-prone tasks. There are numerous instances of complex tasks requiring automation within the electrical domain. Frighteningly difficult examples include the integration of multiple sub-systems into a physical vehicle and subsequent generation of detailed wiring designs; simulation and analysis of complete vehicle electrical systems; and direct-from-data generation of new design drawings that conform to styling requirements and are easily readable.

Configuration complexity. To be competitive in the marketplace modern cars are offered with many customer-chosen options such as left or right hand drive, automatic or manual transmission, gas discharge or halogen headlights, presence or absence of satellite navigation, and much more. The allowable configurations rapidly multiply into many thousands, each of which must be supported by the electrical wiring system. Great efforts are made to control the resultant configuration complexity, for example by “giving away” wires that are not actually used in a particular configuration. However it is neither cost effective nor physically possible for a single harness design to support all possible configurations … again due to the cost and bulk of copper wiring. So it is common for a particular car harness, such as the body harness, to be required in more than a hundred different versions (“derivatives”) at any particular time.

Change complexity. Compounding configuration complexity within the electrical domain is a very rapid rate of detailed design change. This is because wire harnesses are physically flexible and can be adjusted at short notice. So if a new signal must be implemented to meet new emissions requirements; or if an additional clip is required to cure an annoying rattle; or if a connector is obsoleted and a replacement must be substituted, the solution is often accomodated within the electrical wiring design.

These changes must be documented, validated, tracked, costed and passed onwards to manufacturing, logistics and after-sales service systems.

Products Responding to Electrical Complexity.
In order to address these tough challenges Mentor Graphics has developed an all-new suite of electrical design tools, known collectively as CHS. The CHS tools are built on a modern, multi-tier architecture designed to address IT demands for performance, scalability and longevity.

Fundamental to the philosophy of CHS is the belief that design data management is central to solving the problem of electrical design complexity. So CHS is a data centric (as opposed to file centric or drawing centric) toolset, with each software tool built on a common object model. Powerful data management capabilities (such as versioning and design comparison) are provided, and data storage is accomplished via standard Oracle database instances.

With these foundations in place, CHS supports electrical design flows spanning from logical sub-system design, through sub-system integration and wire harness engineering, onto harness manufacturing and (in the future) provision of after-sales service documentation & diagnostics.

The automotive design flows.
It is important to realize that the design flows employed by different OEMs and tier 1 suppliers are quite varied, and cross-organization complexity compounds the diversity. But broadly speaking the following stages can be recognized, though they often occur in parallel and with many repeated iterations:

1. Define the sub-systems (braking, lighting, entertainment etc) in terms of signal connectivity between devices; check system behaviour and validate the design. At this stage multiple types of design data will be available at some level of maturity, for example:
   a. Signal characteristics.
   b. Device pin-out and behaviour.
   c. Early configuration logic.

   Interestingly, physical implementation information may also already be available: some types of signal must be carried on a coaxial cable, for example.

2. Define the physical structure and configuration logic of the vehicle:
   a. Is this a small sports sedan or a large truck?
   b. What types of data networks will be employed?
   c. Where can devices and wiring be placed?
   d. How will wiring be partitioned into individual harnesses?
   e. Will power windows be offered as an option?

   Physical definitions will usually be mastered in MCAD, while configuration logic may be driven from a corporate marketing system.

3. Allocate the devices into physical locations within the vehicle. This may involve agglomeration of several devices into a new one; for example, fuses and relays may be collected into a monolithic power distribution box. Note also that devices may be variantly placed depending on vehicle configuration logic.

4. Integrate the sub-systems and implement the signals with wires. This is a particularly difficult task because the implementation must be as efficient as possible (to save weight and cost) but also respect any implementation requirements and, most difficult of all, consider all possible vehicle configurations. Crucially, this step should not be seen as simple wire routing through a 3D structure. There are other tasks to accomplish that are more electrical than mechanical in nature, for example:

a. Power and ground services must be provided, including special requirements such as ground daisy-chaining.
b. Wire sizes (gauges) must be calculated to meet voltage drop requirements.
c. Wire insulation materials / part numbers must be selected, ideally from a preferred components library, noting performance requirements (temperature, fluid exposure) as well as cost.
d. Multicore cable and shield termination requirements must be met, including special requirements driven by network choices.
e. Splices or multi-terminations must be designed in accordance with corporate practice.

At this point the full electrical / electronic structure of the vehicle is now available, partitioned into harnesses. A further round of simulation and analysis is strongly advisable. There may be critical safety or reliability issues such as sneak circuits that emerge only after integration, for example. More prosaically, the horrible configuration complexity noted above makes a simple error such as pin-to-pin mis-match at an in-line connector difficult to trap.

5. Add mechanical details and engineer harnesses. At this stage the wire harnesses are "bare" collections of wires, splices, multicores and connectors. To assemble fully detailed harness designs a great deal of embellishment is required, such as:
   a. Mechanical components must be added: clips, grommets, protective tubing, tape etc, plus non-electrical bundle inserts such as water pipes. This data is frequently mastered in MCAD.
   b. Component details such as terminal plating material must be chosen.
   c. Configuration-dependent design details must be defined, such as the pattern of wire seals and connector cavity blanking plugs required.
   d. Designs may be adjusted to optimise manufacturing processes; for example, wire part numbers may be rationalized to optimise logistics or the location of a splice may be adjusted to match equipment capabilities.

   Additional important activities at this stage include further design rule checking, design documentation and detailed costing.

6. Prepare data for manufacturing operations. The detailed harness design data can now be leveraged into the downstream harness manufacturing process; for example:
   a. Fully detailed bill of materials (BOM) data can drive corporate ERP purchasing & scheduling systems.
   b. Wire cutting operations can be optimised by consolidating data from many harness designs.
   c. Manufacturing formboard designs can be derived from the detailed harness designs.
   d. Electrical design data can be interfaced to automatic test equipment to ensure that each individual harness is tested correctly.

7. Re-cast the electrical and harness design data for after-sales service documentation and failure diagnostic systems.

This generic process is represented in figure 7. And although it sounds straightforward, the reality is that the concrete boots of complexity make the process mind-bogglingly complicated. For this reason CHS contains powerful technologies that significantly automate the many difficult tasks, providing designers with their lightweight running shoes.

In addition to providing a common, attractive user environment; a very rich data structure; and infrastructure services such as security and data reporting, CHS provides innovative functionality specialized to the electrical domain. This includes:

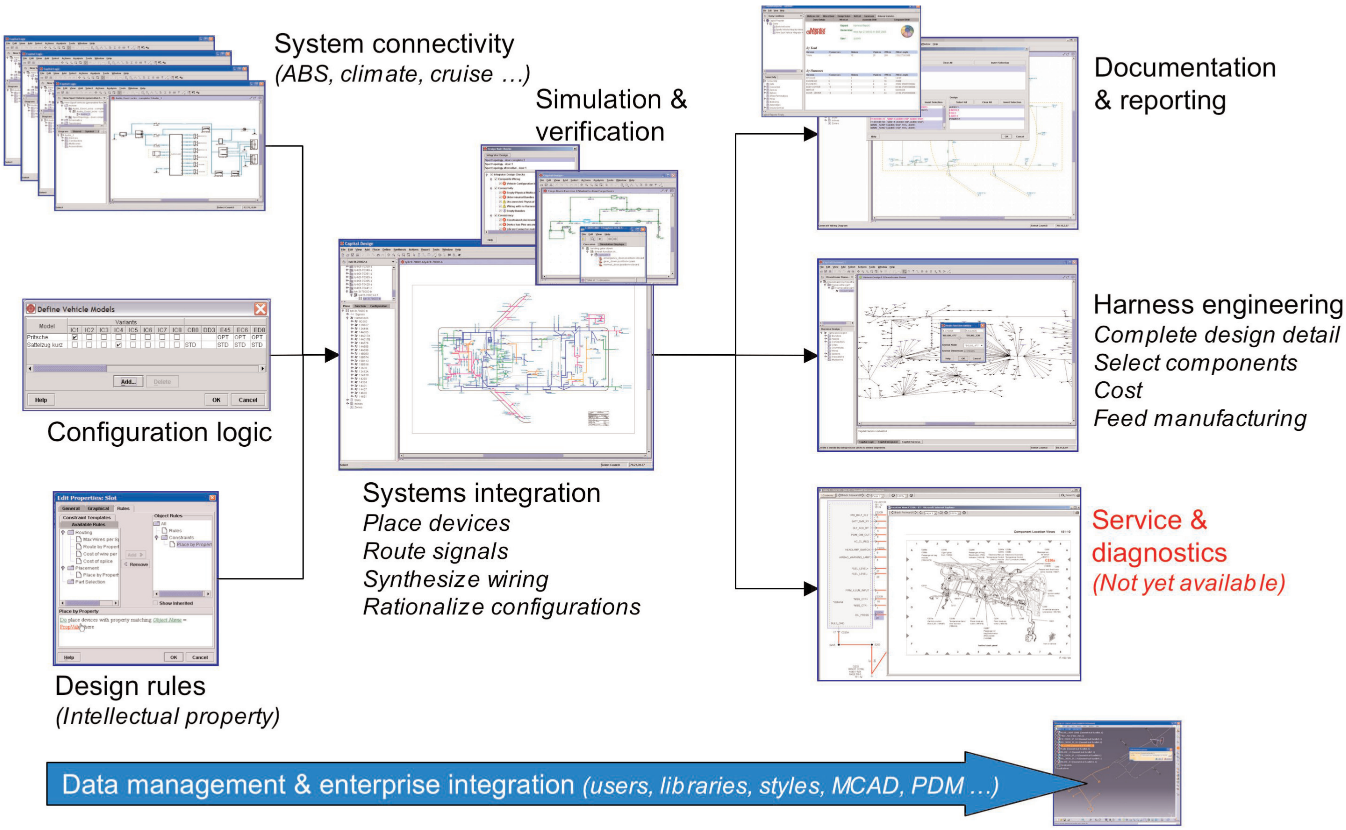


Figure 7: CHS – Automating Systems Integration and Interconnection

Project and process management. Project norms such as naming conventions, design rule check patterns and diagram style templates can be defined and automatically applied. Process constraints such as release management sequence, component usage and analysis scripts can be mandated. Integration with workflow tools is also available.

Design change management. The data-centric architecture of CHS is designed to facilitate change processes. Multiple change management capabilities are provided such as tabular & graphical difference reports; version management; compatibility control ("build lists"); and effectivity tracking.

Deep integration with MCAD platforms such as Dassault Systèmes' CATIA V5 and UGS' Unigraphics NX. Data can be shared either offline or in a live "connected" mode, which aids visualization. Design changes can be trapped and reconciled. PDM integration is also available, for example to slave component library data or to vault released designs.

Cross-organization communication. CHS supports cross-organization data communication at several points in the design flow. Multiple data formats are supported, and specialized functionality such as part number translation is provided.

Configuration capture and composite (superset) data management. Configuration logic can be authored or imported. All design, simulation and reporting activities are undertaken within this composite environment, whether at the full vehicle or individual harness abstraction level. This critical capability further supports easy and robust change management.

Intuitive electrical simulation and analysis. Multiple capabilities are available ranging from simple sub-system behaviour simulation, through quantitative DC and transient simulation, to whole vehicle validation and failure analysis. Fully integrated with the design environment, these tools have been developed for use by all design engineers, not just analysis specialists.

Rules-driven sub-system integration. CHS can automate the key task of sub-system integration using a correct by construction rules-driven paradigm. Corporate intellectual property can be captured and applied to place devices automatically within the vehicle topology and then synthesize the necessary wiring, all in fully composite configuration space. Early stage architectural studies and running production design are both supported.

Diagram synthesis. CHS can automatically generate diagrams from data, so freeing engineers to work on creative design tasks. Style templates can be applied, and drawing contents are laid out for maximum readability.

Harness engineering. CHS provides powerful automatic harness engineering and validation functionality, for example by automatically selecting library components or validating splice balancing rules. Modern construction methods such as modular (sub-assembly) build are fully supported. Very detailed harness costing is available from a model containing over 300 design and process parameters.

Manufacturing feeds. Multiple reports and data interfaces are provided to drive manufacturing operations. A formboard drawing tool is available.

Turning to the software products themselves, within CHS the individual tools are grouped into families that roughly equate with job functions or tasks in the electrical design flow. These families are:

Capital Manager

Data management, storage & reporting services; component libraries; configuration logic; project administration; security.

Capital Design

Signal capture; systems integration; wiring design & validation.

Capital Views

Automated diagram synthesis; diagram styling; data querying.

Capital Analysis

Electrical simulation & analysis; component sizing; electrical design risk management.

Capital Harness

Harness detailing; harness engineering, optimization & validation; component selection; harness costing; manufacturing feeds.

Capital Enterprise

IT environment integration (MCAD, PDM etc); extensibility & customisation.

Importantly, the individual software products within CHS can be adopted progressively or indeed only partly. For example, it is perfectly possible to deploy Capital Design tools together with a third party simulation engine and subsequently to export design data to a third party harness engineering tool. But the seamless integration of the various CHS tools via their common object model, architecture and user interface makes the full suite abnormally powerful.

- Systems Capture & Validation ✔
- Systems Integration & Electrical Distribution Systems Design ✔
- Electrical Distribution Systems Analysis & Verification ✔
- Harness Design, Engineering & Costing ✔
- Support for Harness Production ✔
- Multiple View Synthesis & Reporting ✔
- Enterprise Integration (MCAD, PDM...) ✔
- Component & Design Data Management ✔

Figure 8: CHS is a data-centric solution conceived to support a broad electrical flow from initial capture through build and service

The **Capital Manager** family does not contain purchasable products. Rather, it provides the data and application infrastructure that underpins the individual tools: this infrastructure is provided as an intrinsic part of each core CHS tool (see below). For example, among other tasks Capital Manager provides persistence of data into the underlying database and contains the infrastructure for common functions such as cut-and-paste.

Capital Manager also contains four applications that are fully integrated with the various CHS tools, again provided as intrinsic (no cost) parts of these tools. These applications deliver:

- Component library data, which may in turn be slaved from a corporate library or PDM system.
- Project management functionality such as release management and automatic object naming. Configuration logic such as inclusive / exclusive option relationships may also be defined.
- Highly configurable design data reporting: customized reports can be easily generated via a query user interface, and the output formatted using stylesheets.
- Fine grained user management: for example a user may be restricted to certain activities within certain projects, and barred from everything else.

The **Capital Design family** is concerned with sub-system (ABS, lighting, telematics etc) electrical design, system integration and wiring design. Leveraging the underlying Capital Manager functionality, Capital Design contains three core products:

Capital Capture, which is a low cost schematic capture tool targeted at sub-system designers working at the signal (net) connectivity level. Capital Capture provides an easy to use graphical environment, and writes data in native format for subsequent use by other CHS tools.

Capital Logic, which can accomplish the same tasks as Capital Capture but also author physical wiring designs (splices, multicores, wire colors etc). Capital Logic may be used to design sub-systems but is also used to accomplish interactive system integration, ie the merging of multiple sub-systems into the physical vehicle structure. Capital Logic contains extensive, flexible automation and data management functionality such as design rule checking and design comparison. Critically, Capital Logic manages design data as an entity within composite configuration space, ie fully aware of the vehicle's configuration logic.

Capital Integrator, which provides a breakthrough in the automation of system integration. Employing a correct-by-construction rules paradigm, Capital Integrator automatically merges sub-system signal connectivity, configuration logic and vehicle topology to place devices and synthesize fully composite whole vehicle wiring designs. This removes a huge source of error and design sub-optimization from the system integration task, leaving engineers free to innovate and capture intellectual property via the automation rules. Add-on products extend Capital Integrator's capabilities even further: grounding strategies can be implemented; components (wires, fuses etc) automatically selected based on electrical analysis and component attributes; and wiring diagrams automatically generated (see below).

The **Capital Views** family is comparatively young but contains very powerful automation technology. Fundamentally, Capital Views exists to provide diagrammatic views of electrical designs that have been algorithmically synthesized from data, rather than drawn by human hand. This is because the electrical domain still utilizes diagrams as a key engineering review artefact, and sometimes as a contractual deliverable that conveys either design intent or design implementation. The problem is that there are many types of diagram representing various data abstractions and drawn in various styles. For example, a sub-system based logical diagram looks different from a harness-based wiring diagram, yet they derive from related project data. Manually drawing diagrams is an error-prone and time-consuming task that seriously damages engineering productivity. Capital Views technology seeks to automate this task.

Only one Capital Views product is currently available, **Capital AutoView Assist Integrator**, which generates wiring diagrams from data synthesized by Capital Integrator. These wiring diagrams (containing splices, in-line connectors etc) may be synthesized for sub-systems, harnesses or the entire vehicle, styled following configurable formats, and filtered in several ways. Memory is provided so that manual layout adjustments are not lost when a design change is made.

In the near future several new products will be added to the Capital Views family. These will bring additional, highly flexible data querying and data styling capabilities with the ultimate aim of automatically producing multiple diagram types, ranging from on-demand engineering views to formal after-sales service documentation.

Fully integrated with the Capital Design tools, the **Capital Analysis** family provides a range of simulation and analysis products to aid electrical designers. Starting with low cost qualitative (behavioural: **Capital SimSystem**) and quantitative (DC: **Capital SimWiring** and transient: **Capital SimTransient**) simulation products, this family is designed for everyday use by regular engineers, not electrical analysis specialists. Based on automatically built or industry standard component models (example: VHDL-AMS), Capital Analysis products can run in background to provide instant on-screen feedback to design engineers, with full result reporting capability.

More advanced Capital Analysis products are available to recommend electrical component changes (**Capital SimStress**), rigorously detect unintended circuit functionality such as might be caused by a sneak circuit (**Capital SimProve**) and rigorously compile natural language electrical failure mode and effects (FMEA) reports (**Capital SimCertify**). Analysis scenarios may be scripted for repeated application. Critically, simulation and analysis may be scoped to various design abstractions ranging from parts of individual sub-systems right up to the entire vehicle. And the Capital Analysis products can also leverage CHS's awareness of configuration logic.

Taken together, the Capital Analysis products strongly support the design engineer's daily tasks. But they also provide a powerful environment for managing vehicle electrical reliability, which not only impacts brand image and ultimately corporate revenue but also helps protects against product liability risk.

Moving to the **Capital Harness** family, CHS provides tools to merge electrical wiring data with further mechanical items (clips, grommets, taping etc, frequently mastered in MCAD), complete the design detailing (example: the insulation strip length of a drain wire), automatically select additional component such as terminals and seals, and prepare validated data for manufacture. The core product delivering this capability is **Capital Engineer**, which provides a graphical detailing environment together with powerful automatic engineering functionality to generate the fully detailed harness design and manufacturing bill of materials (MBOM). Multiple output reports are available. And like all CHS products Capital Engineer operates in composite configuration space, making propagation of design changes to the multiple harness derivatives a straightforward task.

Several add-on products are also available for Capital Engineer. One important add-on is **Capital Costing**, which provides highly accurate harness manufacturing costs (process and materials) based on sophisticated models containing more than three hundred adjustable parameters. Another add-on product is **Capital Modular Harness**, which manages the construction of harnesses from sub-assemblies. In addition, data from Capital Engineer can be leveraged right into the harness manufacturing facility to construct detailed, 1:1 formboard drawings; drive wire cutting equipment; program automatic test equipment; and feed ERP systems.

The last family within CHS is named **Capital Enterprise**. Products within this family provide data integration with adjacent software, such as Dassault Systèmes' CATIA V5 MCAD products and UGS' Teamcenter Engineering PDM suite. Going beyond simple data exchange, these bridges also provide functionality to detect and reconcile changes made in the different design domains. Additionally, Capital Enterprise provides the customisation and extensibility mechanism for CHS. For example, customers may wish to automate the release process after a design has successfully passed a set of customized design rule checks. Or they may wish to drive wiring synthesis from a set of externalised rules that embody private corporate intellectual property. Such capabilities are delivered via **Capital Integration Server**, which employs a modern web-based architecture designed to protect customizations when an upgrade to the standard software is made.

9. EMBEDDED SOFTWARE SOLUTIONS

The use of embedded software to provide features that differentiate automotive products in the consumer marketplace is steadily on the rise. Reliable, reusable and transportable embedded software components facilitate design simplification while delivering advanced functionality. In terms of product life-cycle costs, reliability and predictability of software functionality has the potential to dramatically reduce warranty and service costs.

Mentor Graphics Embedded Software Solutions comprise a suite of tools and an integrated software development environment (IDE) together with a large library of proven and reliable software IP products. Core software development tools and applications for automotive design include:

Nucleus™ Edge

Eclipse-based IDE and development tools.

Nucleus BridgePoint

High-level modeling suite for xtUML designs.

Nucleus SIMdx

Complete systems and graphical prototyping.

Nucleus OSEK

OSEK standard Real-Time Operating System.

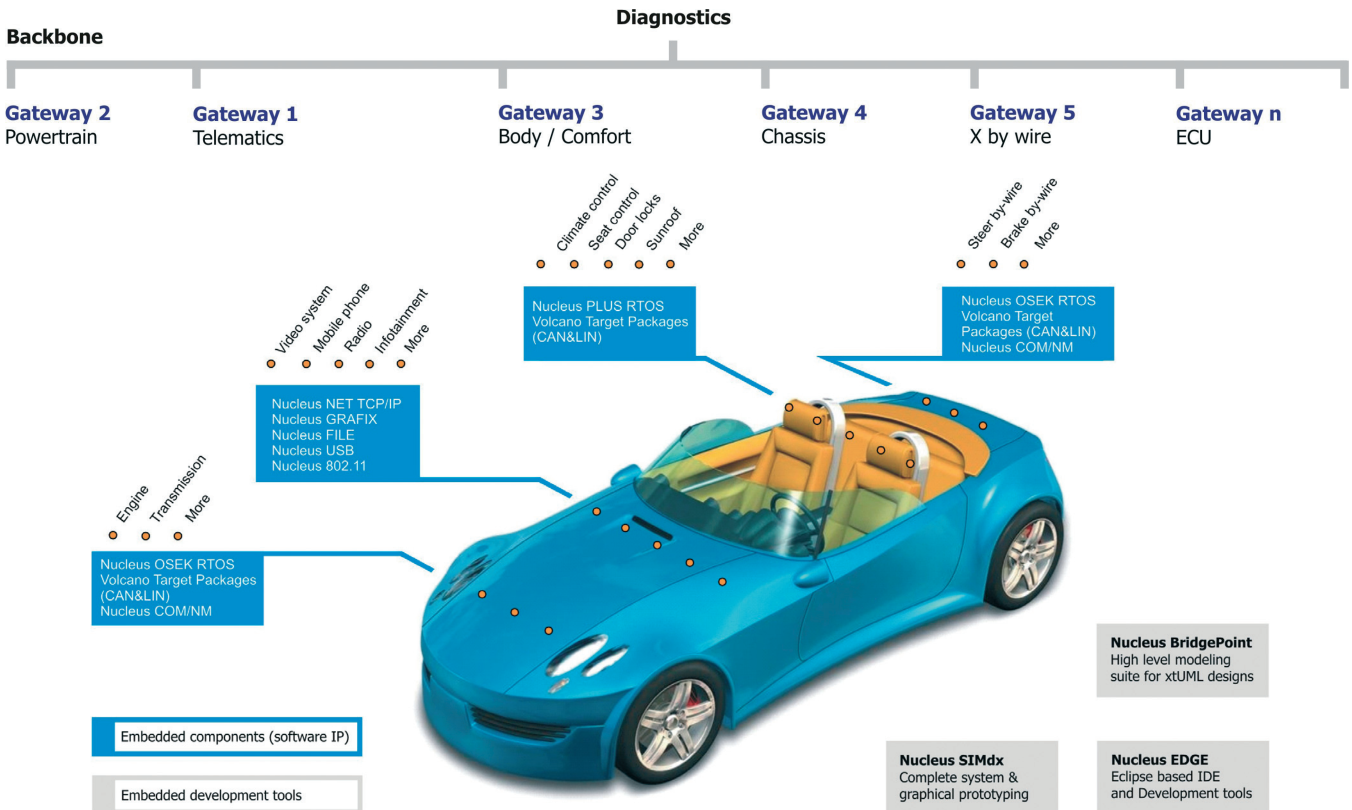


Figure 9: Mentor Graphics Embedded Solutions – Development tools and software IP

This suite of tools provides the engineer with a complete software design flow, from high-level, implementation-independent, UML models right down to on-target debugging and profiling. This design flow facilitates the creation of reliable application code, which is well debugged and validated before it is even executed on the target hardware. High levels of re-usability are achieved with very low defect rates by using Model Driven Architecture (MDA) design with full code-generation, and by validation of the application code in a simulation/prototyping environment. These tools are offered with a set of complimentary software IP components, including a set of real-time operating systems (including OSEK) and middleware. These highly-reliable components allow the designer to focus on his core competence, the operation of the application code, and work with the design tool suite to enable verification of the complete design **Nucleus Edge** provides a consistent, modern and extensible GUI[4] environment, from which the complete tool suite can be operated. Basedon the emerging Eclipse standard, Nucleus EDGE is an IDE that provides an industry-standard framework for interoperation of all the tools the software designer needs for the development flow. Additionally, plug-ins can be obtained from third-parties, or implemented by the user, under the standard API to provide additional functionality customized to a specific task.

The **Nucleus Debugger** component provides an unparalleled array of embedded debugging and source-level analysis tools, including operating system awareness (kernel-level debugging), trace analysis, and post mortem analysis. **Nucleus Profiler** adds advanced

[4] GUI is an acronym for “graphical user interface”

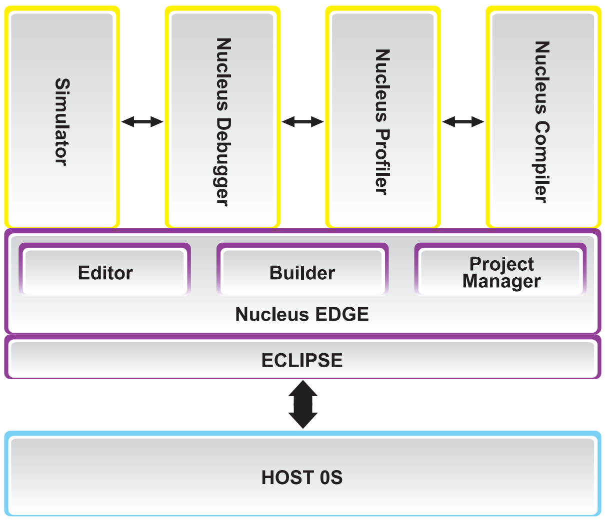


Figure 10: Nucleus EDGE components developed as Eclipse plugins

RTOS-level and custom profiling into the environment. Using Nucleus EDGE, designers can apply their skills across target architectures, tools and host platforms.

Nucleus BridgePoint provides UML[5] capabilities especially for the development of real-time embedded systems. Using the "xtUML" personality of UML2, Nucleus BridgePoint accelerates development and promotes quality by generating code directly from the executable models, and by providing for re-use of existing IP. It is a powerful solution for high-level modeling of automotive applications.

Because Nucleus BridgePoint is based on a personality of UML called "Executable and Translatable UML" (xtUML) all models can be e**X**ecuted at the model level (providing early verification that the model that has been built meets the specification), and all models can be **T**ranslated, i.e. 100 percent of the source code for an embedded system can be generated directly from the high-level design. This combined approach ensures the model which is built is the correct model, and eliminates problems which result from hand-coding, together with many of the problems with traditional UML development methodologies such as the necessity of manually changing code every time a change is made to the model.

Nucleus BridgePoint permits legacy code to be interfaced with generated code and integrates with a wide selection of version control tools. Nucleus BridgePoint tightly integrates with the Nucleus RTOS and the Nucleus Edge development environment.

The benefits of Nucleus BridgePoint have been proven in real applications. It has been used to develop highly demanding systems such as launch vehicles, life-critical medical systems, fault-tolerant telecom systems, resource-constrained consumer electronics and distributed, discrete-event, high level architecture (HLA) simulation systems.

Nucleus SIMdx is a simulation environment that enables developers to run their embedded applications on the development host. It provides the ability to simulate a complete system, including hardware and peripherals, I/O and the application's GUI. Using Nucleus SIMdx, designers can begin software development projects far ahead of hardware availability. Developers can interact directly with the GUI, permitting the validation of all user-interface features, and can be used as a complete working prototype before any hardware is built, again ensuring that the product built is the correct product.

Nucleus SIMdx includes powerful advanced features including visualization, monitoring and tracing tools. Designers can view the interaction of embedded applications, RTOS task activity, and other objects during run-time. Tracing information is displayed for Nucleus tasks, queues, memory usage, network messages, etc., providing powerful operational insight. It also provides expanded network simulation and the ability to run multiple instances of code connected over a network, enabling verification of networked operation.

5 "Unified Modeling Language" Nucleus BridgePoint is fully compliant with the UML 2.0 specification.

Nucleus SIMdx helps designers save time by supporting development not contingent on hardware, and fast debugging in the native environment. It lowers costs by allowing prototyping without requiring expensive hardware, and by producing transportable and reusable applications that can be shared with other developers or used on other vehicle platforms and applications. Overall application quality is improved as a result of early development, allowing more time for applying powerful testing capabilities, facilitating needed modifications to both hardware and software before manufacture.

In complex automotive electronic systems, vital software components developed, simulated and validated using Nucleus development tools run on **Nucleus OSEK** RTOS, a royalty-free, real-time operating system whose resources are statically allocated for mission-critical security. Nucleus OSEK is a full-featured implementation of the OSEK/VDX[6] Operating System developed specifically for embedded applications in the automotive industry. It is fully compliant with the OSEK specification version 2.0.

Written primarily in ANSI C[7], Nucleus OSEK is extremely portable. Typically implemented as a C library, real-time Nucleus OSEK applications are linked with the Nucleus OSEK library; resulting objects may be downloaded to the target or placed in ROM.

Adherence to OSEK standards enhances quality of the software in ECUs. Nucleus OSEK standardizes control unit interfaces among different architectures and optimizes sequenced utilization of resources to enhance overall system performance without adding hardware. Reduced development effort helps reign in costs and yields shorter product time-to-market.

[6] VDX refers to "Vehicle Distributed eXecutive" standard developed by the French car manufacturers **PSA** and **Renault**, who later joined the OSEK group. In 1995 the OSEK/VDX group presented a new OSEK-VDX specification.

[7] ANSI C (Standard C) is one standardized version of the C programming language.

In modern vehicle platforms, consumer electronics and automotive electronics are converging. To manage the growth of electronics while combating complexity and controlling costs, manufacturers will need to rely more and more on embedded software to deliver features demanded by consumers and to differentiate their products. **Mentor Graphics embedded software IP products**, including the Volcano target packages, provide designers with a comprehensive suite of applications for both critical system functionality (safety, powertrain, X-by-wire) and consumer comfort and convenience features (infotainment, telematics, body electronics).

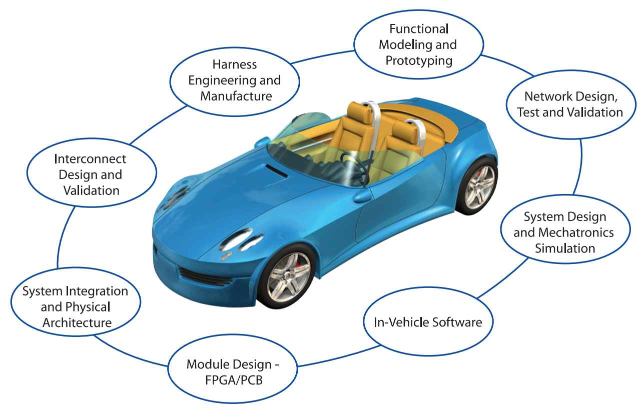


Figure 11: Mentor Graphics Applications for Automotive EE Design Today

10. NAVIGATING THE PATH TO THE FUTURE

The future of automotive EE design lies in more deterministic function-driven design, greater architectural optimization, and adoption of broadly-implemented industry standards (such as AUTOSAR) to better manage technological, legislative and consumer demands.

10.1. AUTOSAR

Mentor Graphics is helping to develop open standards for automotive design. Such standards usually drive further electronic growth. Through its May 2005 acquisition of Volcano Communications Technologies, Mentor is now a premium member of

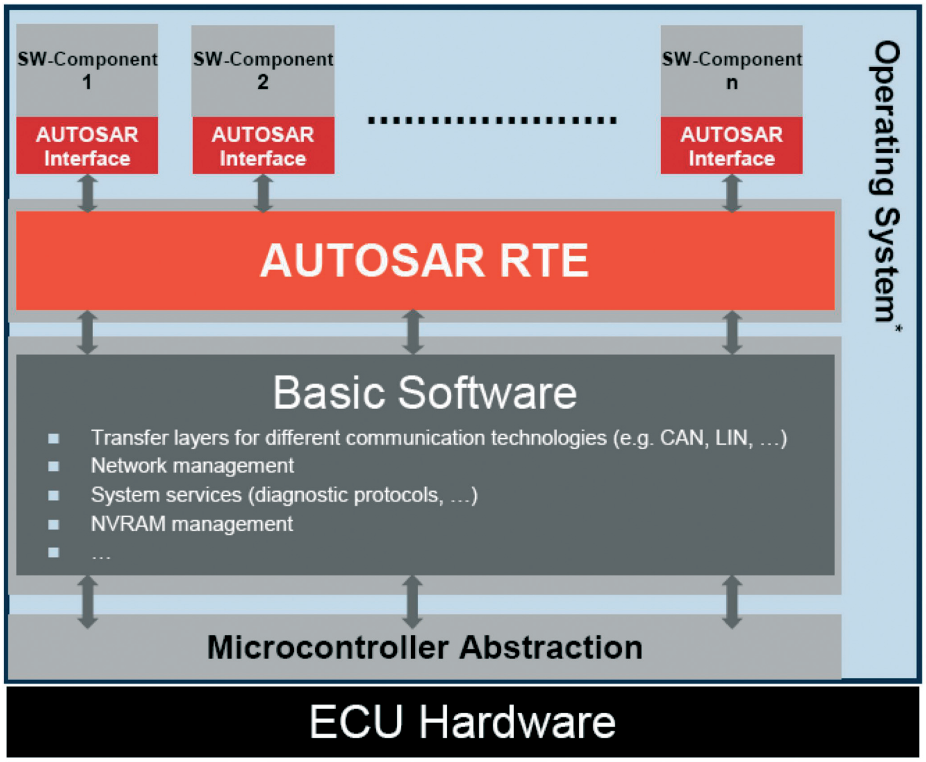


Figure 12: Schematic view of AUTOSAR ECU software architecture

AUTOSAR, the standards association, which includes BMW, Bosch, Daimler Chrysler, Ford and GM as core members. Mentor Graphics is currently the only EDA company that is a premium member of AUTOSAR.

Adoption of the AUTOSAR standard is likely to prove a significant inflection point in the evolution of automotive EE design. Announced in 2003, the AUTOSAR partnership is an alliance of OEM manufacturers and Tier 1 automotive suppliers working together to develop and establish a de-facto open industry standard for automotive EE architecture that will serve as a basic infrastructure for the management of functions within both future applications and standard software modules. The primary goal is to provide standard software APIs that will support development of embedded software as an interchangeable component, similar to hardware components today.

The AUTOSAR standard 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. The AUTOSAR runtime environment is effectively a virtual bus that extracts the application away from the details of the ECU hardware (microcontroller and bus). In this environment, designers will be able to map functions and functional networks to different control nodes in the system, almost independently from the associated hardware.

To achieve the technical goals (modularity, scalability, transferability and reusability of functions), AUTOSAR will provide a common software infrastructure for automotive systems of all vehicle domains based
on standardized interfaces for the different layers shown in figure 12.

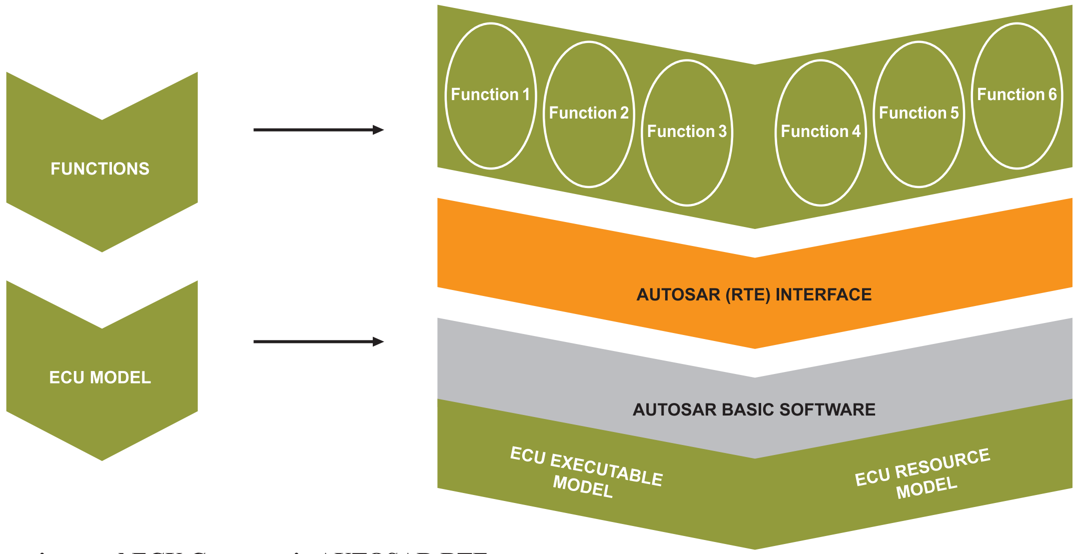


Figure 13: Functions and ECU Connect via AUTOSAR RTE

AUTOSAR will enable both system-wide and configuration process optimization (e.g. partitioning and resource usage) and, where necessary, allow local optimization if required to meet the runtime requirements of specific devices and hardw are constraints.

10.2. X-BY-WIRE TECHNOLOGIES

Increased implementation of X-by-wire systems (steer-by-wire, brake-by-wire, etc.) will further complicate the problems of mechatronic component and subsystem design, heightening the criticality of standardized APIs, tools and practices. With X-by-wire systems, the liability associated with critical platform functions (steering, braking) is effectively assumed by the manufacturer. It is obvious that the need for truly robust system simulation prior to manufacture will become critical. X-by-wire design will make thorough virtual prototyping and verification essential to the reliability and safety of systems and components in order to avoid exposure to costly liability claims. Transferability and cross-domain functional compatibility will become even more important to achieve functional objectives, keep option sets current and competitive, and manage design complexity while controlling costs.

10.3. TARGETED FUNCTIONAL OPTIMIZATION

The percentage of total system functionality that is networked in automotive designs is steadily on the rise. As network complexity rises, there is a greater requirement for emphasis on deterministic design creation, simulation and analysis. Through continued extension of SystemVision, Volcano networking products, interfaces to Simulink, and possible application of existing hardware and software co-verification and modeling capabilities, Mentor Graphics is pursuing a goal of using real embedded software – the actual production code – for system verification.

Through the ability to retarget functionality that will be realized through the AUTOSAR standard, designers will be able to target automotive electronic functions for *any* ECU. This makes possible a system optimization methodology based on movement of functions among ECUs. Possible benefits might include consolidating a function or set of functions that are distributed across several ECUs to enhance performance, or mitigating physical connectivity requirements to help reduce harness complexity and cost. (After engine cost, harness is the most expensive part of an automobile.)

Mentor Graphics is providing the tools and solutions that form the foundation of this future vision today. As the AUTOSAR standard takes hold in the industry, design teams will be able to build on this progressive foundation toward realization of the full power of functional design and architectural optimization.

11. CONCLUSION

Mentor Graphics is leading the way in development of a comprehensive set of solutions for automotive EE design.

Tools, applications and embedded software available now from Mentor represent a full spectrum of products to address formidable challenges from initial component and system design concepts to completely integrated electrical distribution systems.

Mentor Graphics is dedicated to ongoing development of technologies and products that support automotive EE design and manufacturing as growth of in-vehicle electronics and software continues to escalate. Focused on providing the most comprehensive set of solutions for EE design automation, Mentor Graphics is dedicated to helping automotive manufacturers achieve higher product quality at reduced total costs.

Mentor Graphics brings highly-developed expertise and a tradition of successful problem solving in other industries (IC design and verification, integrated PCB-FPGA systems design, etc.) to the challenges of automotive EE design. Combining established and proven technologies with recently acquired or newly developed products targeting the transportation industries, Mentor Graphics is poised to offer uniquely powerful and comprehensive products to industry partners today.

As electrical/electronic and software offerings become more important in terms of both vehicle functionality and customer satisfaction, Mentor will continue to aggressively contribute by providing dynamic solutions that better address:

- Functional design, allocation, and reusability
- System and ECU design and integration
- Vehicle architecture definition and optimization
- Network design and optimization
- Multi-domain analysis
- In-vehicle software and mechatronics design
- Electrical distribution systems design and manufacturing
- Documentation and diagnostics

Additionally, Mentor will continue to create and strengthen strategic alliances and relationships with other key suppliers to the automotive industry such as UGS, The MathWorks, and Dassault Systèmes in order to address the industry need for a complete design environment.

12. ROADMAP TO THE FUTURE

Mentor Graphics vision of the past, present and future of EE design is expressed graphically in a “V diagram” (see figure 14). The diagram illustrates the design process from requirements definition and architectural design all the way down to detailed components. The left side illustrates the design and verification process; test and integration are on the right.

At the base of the V, Mentor Graphics solutions are built on a firm foundation of proven solutions for component design and test, including FPGA/PCB design, automotive harness design and manufacturing, and embedded software. Mentor Graphics today is providing designers of automotive electronics with comprehensive tools for deterministic system and component design, integration and testing. The spectrum of solutions currently available offers tools for design, simulation, integration and testing of

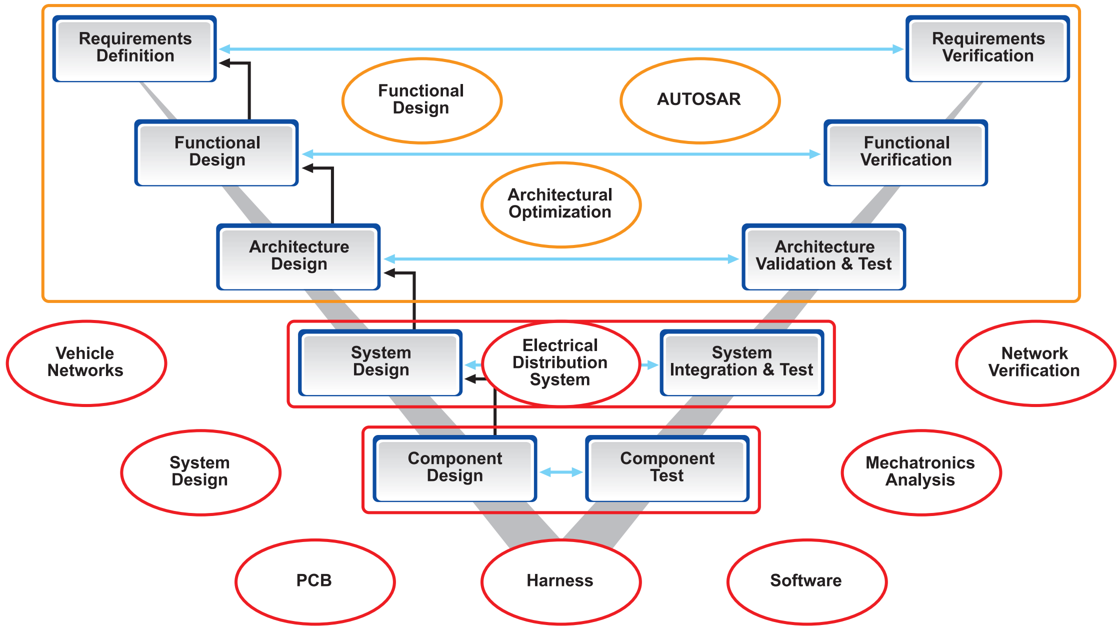


Figure 14: Mentor Graphics is building solutions for the future of Automotive EE Design

automotive electronic systems, including mechatronic subsystems, in-vehicle networks and electrical distribution systems (second and third levels of the V). By emphasizing modeling, analysis and simulation of virtual prototypes prior to integration and testing, these solutions deliver design efficiencies that enhance reliability and help reduce escalating product warranty costs.

Mentor Graphics conceives the future of automotive EE design as embracing the concepts of architectural optimization, functional design and standardized APIs such as AUTOSAR that allow treatment of embedded software as an interchangeable component (top levels of the V diagram). Standardization of the interface between functions and ECUs will allow designers to verify designs using the actual embedded software and selectively target functions to ECUs. System optimization through movement, distribution or consolidation of functions on ECUs allows for the best possible expression of functionality and efficiency at the lowest cost. Cost-effective design and high product reliability support nimble response to the marketplace, lower warranty exposure, and an improved bottom line for automotive manufacturers.

Mentor Graphics is committed to this vision of the future and to development of solutions that will help automotive EE designers realize the substantial benefits it will bring.

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