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Engineering smart control systems

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Smart system design

Automotive manufacturers worldwide are under pressure to stay technologically ahead of their competition and to develop cutting-edge products that are less expensive on the one hand and more fun to drive on the other. In addition, governmental regulations and industry standards, such as ISO 26262, require manufacturers to produce more eco-friendly, safe and smart products.

To achieve these goals, car makers are applying mechatronic solutions to develop breakthrough products with brand-differentiating functionalities. Mechatronic solutions leverage electronics and software in advanced control systems to optimize the performance and efficiency of the mechanical system.

Mechatronic solutions result in smart systems that not only adapt to human driving patterns, but also to the operating environment and to the state of the vehicle. In addition, they incorporate prognostics and diagnostics to ensure that the vehicle operates well within its performance envelope and any deviation from this performance envelope is managed to ensure the safety of the vehicle occupants.

Developing a successful mechatronic solution requires optimizing the mechanics, electronics and software simultaneously as an integrated system. This goal can be accomplished using a model-based system engineering (MBSE) approach that enables engineers to quickly evaluate the performance of a wide range of design concepts without physical hardware.

Combining experience, skills and technology

The track record of LMS™ Engineering services is proven in succesfully delivering tools and solutions. LMS Engineering integrates test and simulation in mechanical and controls development for smart systems design. As technology innovators and partners for European Commission-funded research programs, State-of-the-art verification and validation methods were devised and successfully deployed. LMS™ solutions apply processes and methods in accordance with ISO 26262 recommendations to verify the functionality of the system and its associated safety measures. LMS Engineering provides a worldwide team of highly skilled experts that can assist in developing and deploying functionally safe and reliable control system features throughout the phases of the development process.


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Challenges of smart system design

LMS Engineering has developed a comprehensive MBSE approach that integrates simulation and test to help car manufacturers answer the key industry challenges and develop best-in-class mechatronic solutions.

How to develop high-quality controls in less time

World-class control system design processes and methods are crucial to developing, deploying and improving high-quality system-specific controls in a minimum amount of time.

Relying on domain, tool and embedded software experience, LMS Engineering has developed structured customer-specific development processes to efficiently deliver high-quality control software. Its requirements-driven approach offers a one-stop solution to mechatronic system development, resulting in an implementable control system structure that can directly be used for automatic code generation.

LMS Engineering has wide experience in all phases of the controls development process including requirements definition, systems integration, testing and final calibration. In addition to applying best practices in controls development processes and software tools, it is also proficient in advanced control techniques, such as model-embedded control (MEC) and model-predictive control (MPC). Its experience includes internal combustion engines, hybrid engines, transmissions, energy storage and chassis applications.

How to reduce experimental testing costs

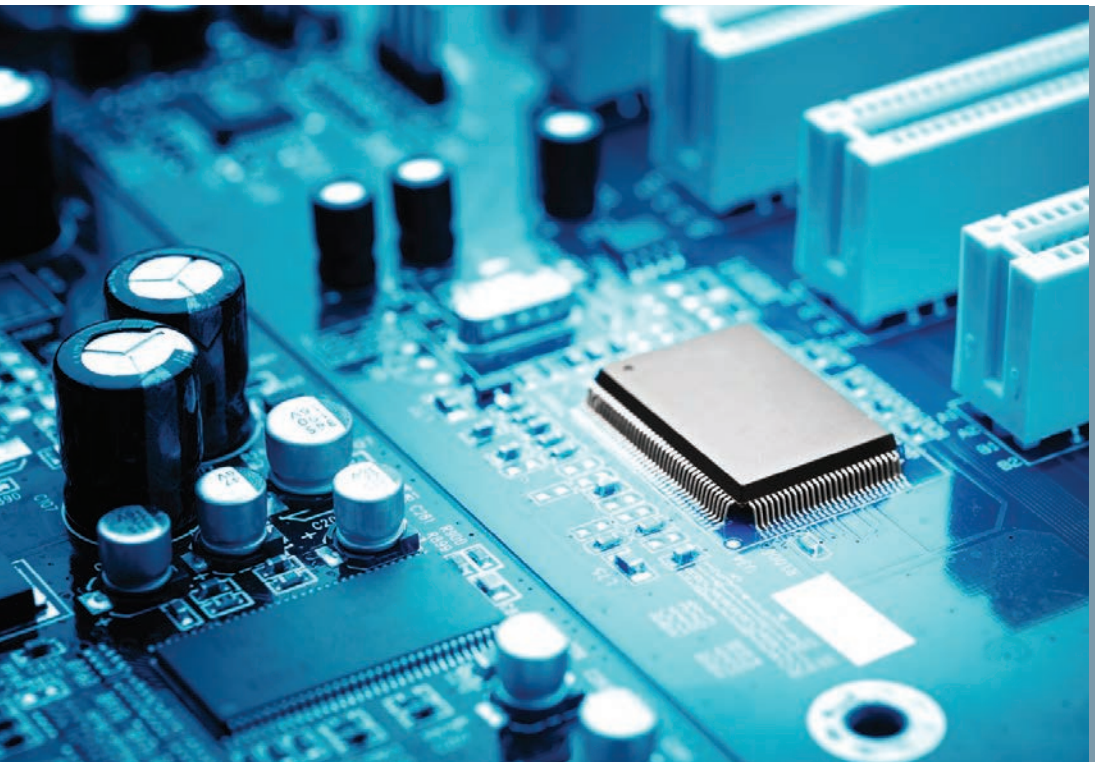
Car manufacturers need to avoid the time-consuming and expensive traditional hardware-based build-test-fix process.

The LMS Engineering approach enables early decision making and early identification of issues by proceeding with control system development before availability of prototype hardware. Plant models and controller-executable specification models help LMS engineers and their customers perform upfront verification and validation of control systems in order to achieve higher levels of quality, safety and reliability at a lower cost.

Testing can also be done virtually through model-based closed-loop simulation of the control software. Performing low-cost software-based build-test-fix cycles at multiple milestones substantially reduces the required number of expensive hardware-based design iterations.

How to manage system complexity

The transformation of a purely mechanical system to a mechatronic system significantly increases system complexity. The development and implementation of a mechatronic solution needs to be carefully managed to avoid vehicle problems and warranty claims.



ISO 26262 – Functional safety in the automotive industry
Functional safety features form an integral part of each product development phase, including specification, design, implementation, integration, verification, validation, and finally, production release. ISO 26262 defines functional safety for automotive equipment applicable throughout the lifecycle of automotive electronic and electrical safety-related systems.

LMS Imagine.Lab Amesim™ software delivers a scalable modeling platform that offers a viable path to smart mechatronic solutions. The LMS Amesim platform provides offline and real-time modeling infrastructure ranging from simple maps to fully detailed physics models. LMS solutions help customers set up virtual test platforms and design processes to support controls development for vehicle energy management, chassis and powertrain.

How to increase productivity when working with global teams on multiple product programs

Managing and sharing models and other information can be challenging when working collaboratively with a global team spread over multiple time zones. It is even more challenging when supporting several product programs for different markets.

The LMS system data management solution of LMS, LMS Imagine.Lab™ Sysdm software, provides a structured approach to managing distributed collaborative design simulation models. The LMS Sysdm platform can be used to seamlessly archive, share and retrieve models and their associated data and test results.

LMS Imagine.Lab™ System Synthesis software is an architecture-driven development tool that enables managing, sharing, synchronization and merging of virtual vehicle prototype models across the global team.

Develop control strategy

Design high-quality controls in the least possible time

Control strategy design involves developing a control system that effectively drives the actuators to achieve the desired system behavior with a limited set of measured variables in the presence of disturbances, measurement noise and part variations.

Unique controls development process

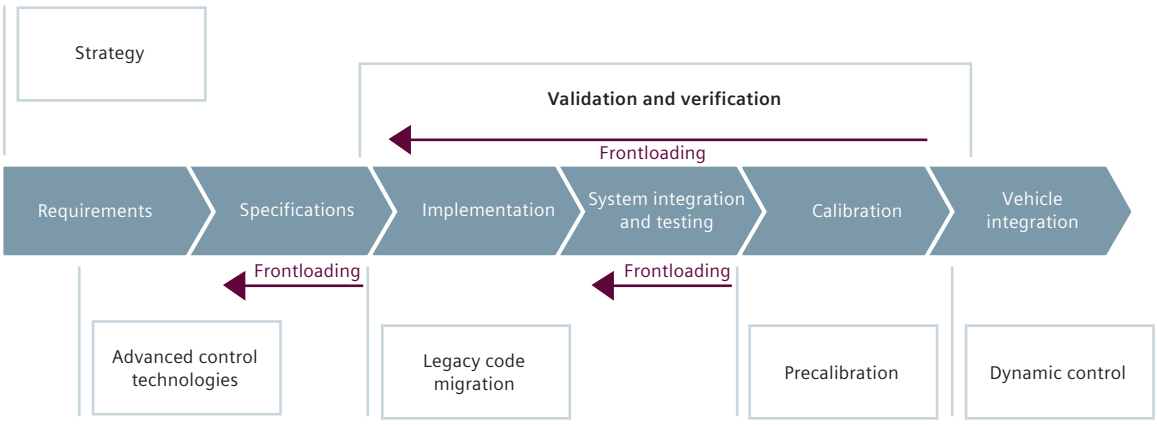
The LMS model-based approach to control strategy development delivers an implementable control system structure that can be directly used to automatically generate code for the target application. The LMS approach helps customers develop, deploy and continuously improve an organization-specific controls development process. From requirements, system integration and testing to final calibration, hands-on MBSE experience is leveraged to help customers concurrently develop the physical system and its associated controller.

Proven code generation strategy

One of the advantages of using a model-based approach to controller development is the ability to generate embedded software in the form of C-code directly from the models. LMS Engineering has developed structured application-specific models and code generation processes that produce high-quality control software with minimal development times. LMS engineers utilize domain, tool and embedded software experience while complying with organization-specific standards to set up the modeling and code generation process so that the generated software is optimized.

Mastering advanced control techniques

Control strategy development is more than just creating logic flow diagrams. Some controller functions are based on advanced algorithms that require deep physical insight and high-level mathematics. LMS engineers successfully collaborate with academia and advanced research groups in the industry to apply advanced research theory to real-world problems.



Adding value in developing control strategy

- Fundamental knowledge of physical systems
- Domain and development expertise, from concept to deployment and field debugging
- Solid understanding of engineering tools and methodologies
- Experience in leveraging information science for data management

Model-predictive control (MPC)

Model-predictive control (MPC) provides a systematic approach for designing highly complex multivariable control systems. Essentially, the MPC approach optimizes a control objective over a finite horizon in the future, using a system model to predict the system response. A fundamental advantage of MPC is that system limitations are explicitly taken into account in the controller description by adding them as constraints to the optimization problem. Consequently, the controller can exploit the full system performance.

MPC also provides a systematic, streamlined procedure to a) analyze a model's level of accuracy and complexity; b) create compact control models, preferably directly from a high-fidelity system model; c) analyze the performance and computational complexity of the resulting controller when simulated in closed-loop with the high-fidelity plant model and d) assess the system performance envelope by adjusting the control objective.

Model-embedded control (MEC)

During early concept design, engineers use simulation tools such as LMS Amesim to predict system performance. For mechatronic systems, the controller must be designed to evaluate the plant. If the system does not meet the requirements, is it because the plant is inherently flawed or because the controller was not properly designed? The attempt to answer this question might lead to escalating project costs as controls engineers try to reduce uncertainty in their analysis.

Model-embedded control (MEC) is a numerical technique that automatically generates the optimal control trajectories for a given plant model. The controller uses a copy of the plant model to evaluate possible control actions, returning the action that achieves the user-specified objective.

MEC provides an upper limit of performance by determining that certain systems will never meet the requirements. This approach makes it possible to quickly zero in on the best possible design. By focusing on what the controller should do, and not on how it should do so, MEC also provides more concrete controller requirements and insight into good control strategies.

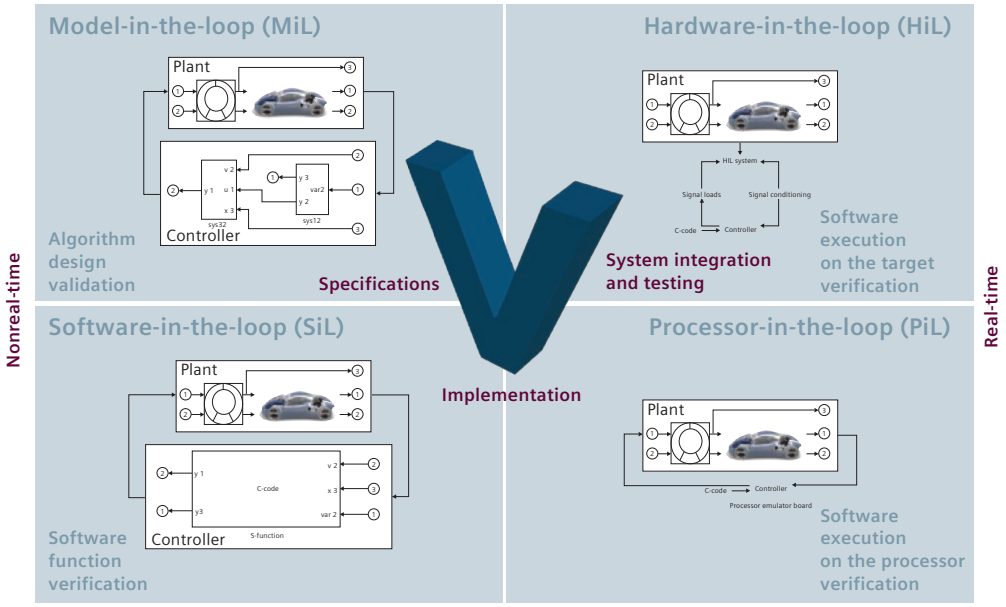
Develop controls earlier in design process

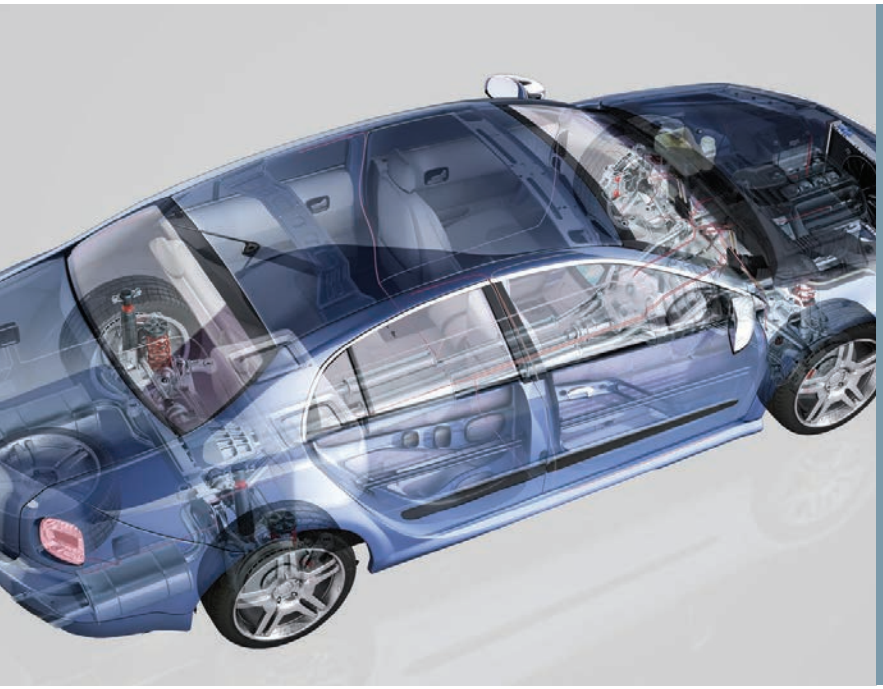
Reduce costs of experimental testing

The model-based control system development process significantly boosts the maturity of the control system by testing control algorithms as virtual systems well before they are implemented and integrated as software. The use of plant models and controller executable specification models makes it possible to verify and validate control systems against all the desired functional requirements in the early stages of the design process. This approach provides high confidence in the functionality of the controller software at the validation stage.

Virtual verification and validation

Traditional verification and validation (V&V) techniques are time-consuming and expensive because they rely mostly on physical prototypes. On the other hand, the LMS MBSE process for development of control systems for mechatronic applications uses controller and plant models to perform V&V early at different milestone gateways in the design process. This approach supports critical requirements in engineering, test procedures development and test criteria development for software V&V. As a result, it helps achieve higher levels of quality, safety, reliability and efficiency.





Compressing the controls development process

- Process and domain expertise
- Expertise in development and deployment of various test platforms: MiL, SiL, HiL
- Extensive experience in specific tools for automatic test case generation and execution
- Large-scale testing solution through virtual test farms to test and validate mass production embedded systems
- Quick and robust approach
- Modeling and co-simulation of hardware and software
- Savings of time and money
- Total quality assurance

Requirements engineering

LMS Engineering uses requirements engineering and analysis as is the cornerstone for V&V activities. Starting from design intent and related system performance requirements, state-of-the-art optimization and design trade-off techniques are used to engineer the subsystem and component-level requirements of the system. In addition, LMS Engineering has considerable experience in organizing and managing requirements and using traceability analysis to link requirements with design features and test cases.

Test case development

LMS Engineering develops test cases based on requirements analysis independent of the controller design as well as structural coverage-based analysis of the controller models. This process enables the testing of both intended and unintended behavior. As part of test case generation services, customized tools for automated test case generation and execution that significantly reduces the testing time and effort are provided. Detailed test procedure documents for independent V&V teams are also available for companies requiring minimal support for testing. The test procedures are test platform-independent and hence enable re-use across various stages of the controller V&V.

Test platform setup

Through targeted application of MBSE-related technologies, LMS Engineering develops and deploys various contol test platforms, such as model-in-the-loop (MiL), software-in-the-loop (SiL) and hardware-in-the-loop (HiL). LMS Engineering properly extracts the controller software architecture and creates executable test harnesses for the different test platforms. These harnesses provide test inputs and capture results.

Hybrid HiL (HyHiL) testing

The simulation platform LMS Amesim can be used to develop highly accurate real-time models. However, some vehicle systems are difficult to model in real-time applications. LMS Engineering meets this challenge by providing Hybrid HiL (HyHiL) testing that includes integration of a mechanical system with a real-time vehicle model in a dedicated test rig.

Virtual test farms

For large-scale product verification and validation, LMS Engineering offers virtual test farms to test and validate mass production-embedded systems, especially the software executing on the target hardware. These virtual test farms simulate vehicles running in closed-loop with ECUs under different test profiles. LMS Engineering has extensive experience with test farms and continuously builds and maintains test benches to service customer orders. Virtual test farms offer many advantages. ECU prototype and production intent releases are verified in closed-loop with the virtual vehicle using test cases generated from product requirements provided by the customer. Regression tests verify the integrity of the ECU functionality when new features are added to meet new requirements or fix bugs. Verification reports evaluate ECU quality. Virtual test farms also substantially reduce mechatronic solution development expenses.

Test execution, analysis and reporting

LMS Engineering performs extensive V&V on specific XiL test platforms during the development stage and provides design quality evaluation reports. In addition to numerical testing, custom tools for product style-checking that support standard and custom guidelines are provided to ensure that the design is consistent in style across different work streams.

ECU reverse engineering

Leveraging its experience with embedded software, LMS Engineering can generate a high-level control strategy from an existing ECU implementation. With ECU hardware and I/O input, a harness is created to test specific load profiles on the ECU and determines the high-level strategy implemented within the ECU. This functional representation of the embedded software is used for high-level design studies.

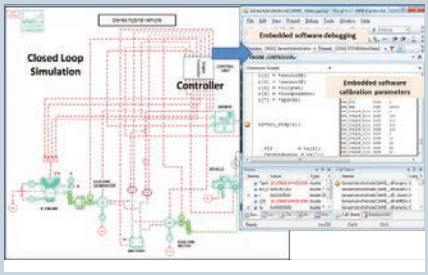
Reduce calibration time with model-based precalibration

Traditionally, controllers are calibrated with the actual physical hardware that is being controlled. Model-based precalibration of the control software provides a cost-effective way to perform this step earlier in the development process, resulting in higher product quality. For instance, the engine management system executing on an engine control unit is calibrated on an engine dynamometer or on a vehicle with the target engine. This calibration process has to wait until the physical hardware is ready which significantly delays the development process. In addition, the embedded software is calibrated on the actual hardware late in the development when changes to the hardware for performance improvement are very expensive.

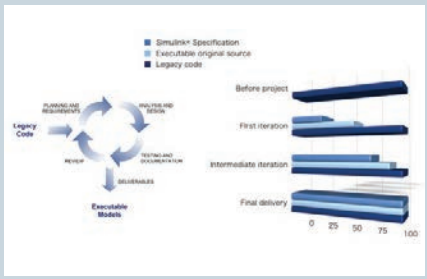
Model-based precalibration involves calibration of the embedded software in a virtual system platform instead of the physical hardware. The controller is simulated in closed-loop and the system dynamics and the calibration process steps are executed on this virtual system. For example, if the controller is available as a Simulink® environment executable, then LMS Amesim plant models can co-simulate with the controller and special MATLAB® environment tools can be used to calibrate the controller in the desktop environment.

Accurate migration of embedded C-code

Most automotive manufacturers have accumulated years of system controller knowledge within their embedded C-code. Leveraging this knowledge while transitioning to an MBSE process requires migrating the C-code into other models such as MATLAB and Simulink and the Stateflow® environment.



Pre-calibration of Embedded Controller software on a virtual vehicle in LMS AMESim.



LMS customized solution for migrating legacy C-code to control models.

LMS Engineering has developed an optimized, customizable process with associated tools for migrating legacy ECU code to control models in conformance with the MBSE paradigm shift. The resulting MATLAB and Simulink models are to be equivalent to the original C-code while providing increased readability, which enables auto-code generation. Leveraging these processes and tools, LMS Engineering offers a scalable service to perform the migration, resulting in production code for ECU control units.

Both hardware and software can be modeled and co-simulated, facilitating the frontloading of the testing and calibration phase. Virtual integration identifies design faults early in the design cycle, providing substantial time and cost savings. LMS Engineering supports both literal translation of legacy code to low-level Simulink blocks and intent-based translation from design requirements to Simulink. LMS' MBSE approach enables functional performance between the legacy code and Simulink models, as well as verification of auto-generated code against the original legacy code.

Scalable design choices

Design high-quality controls in the least possible time

LMS Amesim is an integrated platform for multi-physics system simulation. Its scalable modeling environment allows users to build physical system models for controller testing in a non-real-time desktop workstation environment and for real-time HiL applications. LMS Amesim enables closed-loop testing and validation of the controller earlier in the process using controller models with MiL, implemented embedded software testing with SiL, and, finally, the embedded code running on the target using HiL.

LMS Engineering assists customers by developing appropriate levels of detail in the control-oriented models of mechatronic systems and setting up appropriate modeling infrastructure, virtual test platforms and design processes to support controls development.

Vehicle energy management

The development and testing of sophisticated control strategies is an integral part of the Vehicle Energy Management and Thermal Management solution. LMS Imagine.Lab Vehicle Energy Management helps manufacturers integrate green engineering into the concurrent development process while combining mechanical, thermal, electrical, and controls engineering in one synthesis platform. With its vast library set and its open interface to controller modeling tools, LMS Engineering provides strategic advantages to companies seeking to develop products right the first time are provided.

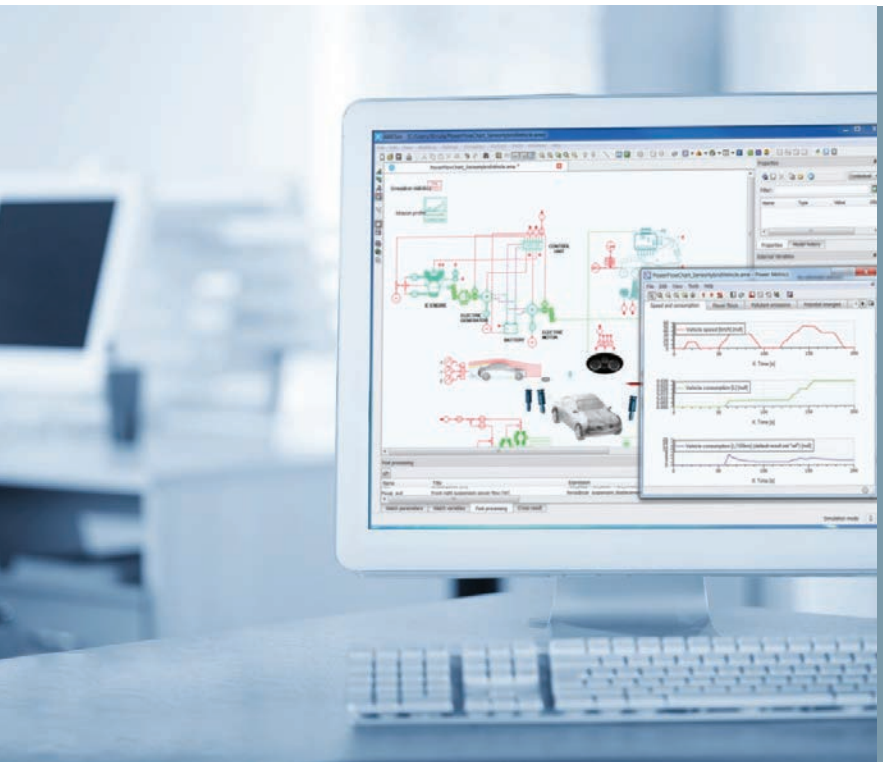
LMS Engineering pioneers a full vehicle test approach for vehicle energy management, complementing the traditional full vehicle evaluation with detailed instrumentation and measurement of torque, temperatures, flows, and currents. The LMS Engineering approach includes an optimized robot driver to enable maximum data accuracy and consistency.

This approach collects high-quality data while reducing testing time by eliminating the need to gather subsystem data from separate testing activities. Benchmarking and in-depth competitive investigations can be quickly completed.

Vehicle chassis controller for brand differentiating driving dynamics

LMS Imagine.Lab Vehicle System Dynamics provides the ability to model individual chassis system components such as brakes, suspension, steering and anti-roll systems, and integrate them in a single system model to simulate and validate global chassis control strategies. In addition, LMS Amesim has a rich set of scenarios to evaluate the chassis control system in standard driving maneuvers used by industry and government agencies. This approach can be used to model and simulate different actuator technologies and vehicles with different levels of modeling detail.

Reliable testing of cutting-edge systems such as electronic stability program, roll stability control, active suspension and active rear steering is made possible through the ability of LMS Amesim open architecture to interface with embedded C-code and control system modeling tools such as Simulink.



Managing system complexity

- Representative plant models usable by both the design and control team
- Optimal compromise between accuracy and execution time
- Continuity in design process: MiL, SiL, HiL, precalibration
- Increased productivity and shortened time-to-market of new products
- Mix of multi-disciplinary system design inside the real-time loop: jump from offline to online design
- Balances vehicle energy performances with drivability and thermal comfort

Exceptional driving experience through enhanced powertrain controls

The complexity of powertrain control systems has increased rapidly in recent years with the advent of new types of engine and transmission actuators and fundamental breakthroughs in reducing losses and waste energy recovery technologies. These technologies demand a fundamental increase in the sophistication of the control system. Modeling is equally essential to develop an optimal control solution for these technologies.

With its vast thermal, hydraulic, electrical and mechanical libraries and components, LMS Amesim offers a powerful platform to model system dynamics using a component-based approach. The performance impact of a new actuator can be evaluated in conjunction with control before committing to hardware prototypes. The use of models earlier in the design process results in more easily controlled physical system designs. This increases the quality and productivity of the design process. LMS Amesim libraries support the development of both conventional powertrain systems and new technology vehicles such as battery electric vehicles (BEVs), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEV)s, and fuel cell vehicles (FCVs). Standard drive scenarios for fuel economy and emission prediction are also included.

Integrate infrastructure

Increase productivity with global teams working on multiple market-specific product programs

Global productive teams often find it difficult to share information and manage multiple projects. The trend toward providing market-specific or personalized products across the globe presents the additional challenge of managing multiple product lines simultaneously. The solution for system data management, LMS Sysdm, provides a structured approach to manage distributed collaborative design models. The models and their associated data and test results can be seamlessly archived, shared and retrieved.

LMS System Synthesis together with Sysdm provides an integrated environment to increase engineers' productivity and creativity in the development of multiple market-specific products. These new generation tools help users understand, manage and share evolving design concepts such as architectures and variants while linking to modeling tools such as LMS Amesim and Simulink to drive appropriate mechatronic design decisions.

Manage and share collaborative designs

LMS Sysdm is a central database system for managing component and system-level models, including the associated data for calibration or usage profiles. It provides a collaborative environment for MBSE data. The repository system enables engineers to create an organizational model for managing system simulation data, facilitating classification, and data query and retrieval according to relevant schemas.

LMS Sysdm features version control and variant system model management for lifecycle management throughout the design process. It includes role-based access control, allowing structured collaboration between departmental teams of system model developers, system engineers and project managers.

Manage multiple architecture variants

LMS System Synthesis is an open environment that integrates multi-physics systems models and related controls models to enable architecture-driven development of mechatronic systems. The architecture-driven development process follows a top-down methodology, starting from creating or importing tool-neutral architecture, configuring models and libraries such as LMS Amesim, Simulink, C-code and others, and co-simulating in target platforms. LMS System Synthesis enables system engineers and architects to seamlessly work on conceptual design and system architecture, integration and validation using data and models originating from multiple applications. The end result is an executable system model that can be used for validating and optimizing overall system concepts in different test scenarios.

LMS Imagine.Lab Sysdm benefits

- Facilitates updating and sharing, as well as structuring the collaboration workflow
- Improves simulation data quality and traceability
- Increases productivity
- Accelerates distributed decision-making
- Safeguards company IP
- Integrates with product lifecycle management (PLM) enterprise applications

LMS Imagine.Lab System Synthesis benefits

- Significantly reduces system integration time and effort
- Enables global collaboration and synchronized development
- Displays reference architectures that can be used to generate multiple system simulation models
- Any change in the architecture is easily transferred to the other simulation models

LMS Engineering

Smart technologies. Unique solutions.

LMS Engineering offers a unique combination of development experience, engineering skills, and application know-how to help customers build re-usable, reconfigurable architectures for controls development.

Combining experience, skills and technology

LMS Engineering supports organizations with control development activities in multiple ways:

- Takes full development responsibility for the (sub)system and delivers a fully realized controller
- Takes responsibility for specific stages in the controller design process, such as: specification development, integration and testing, and works closely with organizations to successfully develop and deploy embedded controllers
- Implements and deploys specific controller development environments to enable customers to deliver high-quality control systems in a minimum amount of time

Vehicle performance engineering

The LMS Engineering team has extensive experience in integrating engineering change orders (ECO) into the current development process while continuing to improve the car's performance and brand image. LMS engineers' expertise ranges across multiple physics domains including mechanical, thermal, combustion, electrical and controls.

Sharing best practices

LMS Engineering provides a lasting return on investment through an open working relationship and a direct transfer of knowledge and best practices to its customers. Backed by a large software development team, innovative tools and methodologies to eliminate process bottlenecks are developed and deployed.

With its broad experience in industry-wide MBSE process best practices, the team works closely with customers to identify the current status of the customer's processes and to recommend appropriate process and tool changes to improve efficiency and quality.

Benefits of working with LMS Engineering

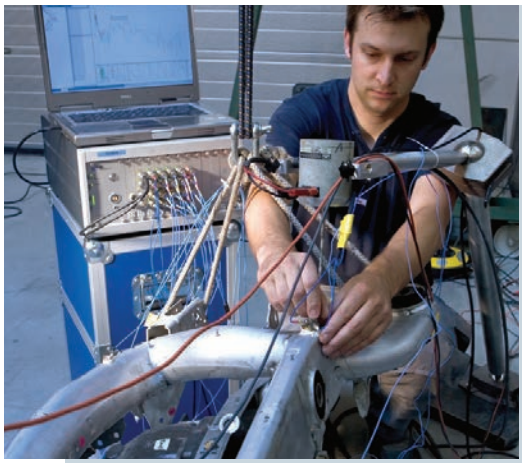
- Combined test and simulation approach
- Transferring technology
- Enables parallel development
- Experienced and skilled team

Engineering skills and worldwide development support

LMS Engineering is experienced in global program management. Driven by a results-oriented philosophy, the project teams are committed to achieving customers' target goals, within budget and on deadline.

With over 30 years of experience, 7500 projects successfully completed, and more than 200 experts on over three continents, LMS Engineering offers the prime technology-driven solutions for controls development.

Applications

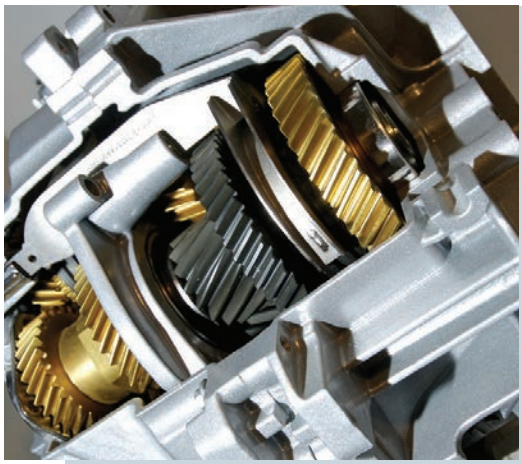


Chassis

LMS Engineering offers dedicated solutions to make decisions early in the design process for chassis-system assemblies, like brakes, suspension, steering and anti-roll systems. Chassis assemblies can be integrated into a single system model to simulate and validate global chassis control strategies. A scalable approach is offered to model and simulate actuators and the vehicle itself ranging from functional to multi-body approaches. The solution offers straightforward integration with MiL, SiL and HiL validation processes.

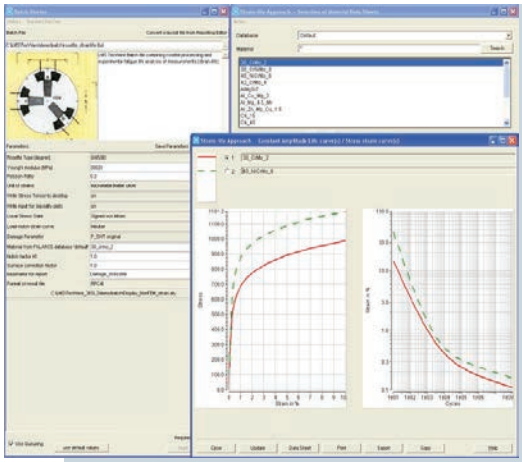
Internal combustion engine

LMS Engineering helps customers design comprehensive engine systems such as fuel injection, air management and combustion and engine control strategies. LMS Engineering provides accurate engine models and domain expertise in components controls and process requirements. The impact of innovative technology choices, such as advanced valve-train systems, multiple injection and multi-stage turbochargers is thoroughly analyzed .



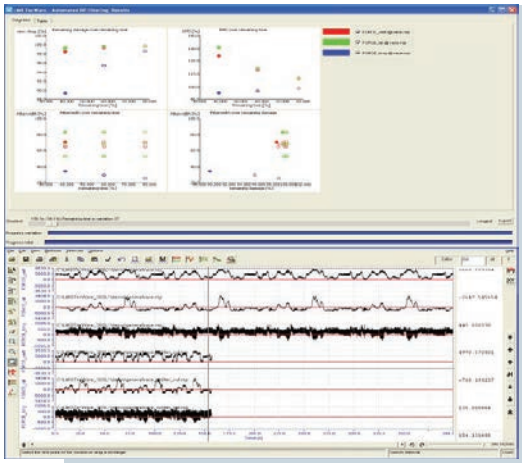
Driveline and transmission

LMS Engineering facilitates the simulation of new transmission designs along with control strategy concepts. The LMS solution provides a comprehensive, flexible development framework ranging from component design to system integration and control validation for any kind of transmission architecture including hybrid, dual-clutch, robotized, automatic and continuously variable transmission (CVT). This technology provides a scalable solution to address not only drivability, but also judder and high-frequency driveline integration and comfort issues.



Battery and fuel cell management

LMS Engineering offers battery and fuel cell plant modeling technology together with practical experience in battery management system development. LMS Engineering has proven expertise in battery management system strategies such as state of charge, state of power and state of health estimations and testing on MiL, SiL, and HiL platforms to support the requirements, implementation and validation phases.



Vehicle energy management

LMS Engineering addresses the challenge of integrating innovative eco-friendly powertrain concepts, while continuing to improve the car's drivability, comfort and performance. The LMS methodology supports conceptual architectural design iterations for HEV, EV and ICE and mild hybrid vehicles. It can be used to evaluate and optimize subsystem performance during later development phases. Designed for integration into the existing vehicle development process, the LMS approach combines mechanical, thermal, electrical, and controls engineering in one platform.

Off-road vehicles

LMS Engineering provides model-based solutions for evaluating and balancing requirements like speed, precision, stability, driver comfort, load hoisting, and power supply dimensioning for hydraulic or electric drives on off-road vehicles. With complex interaction between mechanical and hydraulic subsystems and control elements, only a total system simulation provides representative results. Geometry-based capabilities to model vehicles, such as wheeled or crawler loaders and backhoes, cranes, skid steers or forklifts, are complemented with 1D functional simulation for transmission systems, driven by the control unit. The simulation also covers the engine's power supply and the hydraulic circuits.

About Siemens PLM Software
Siemens PLM Software, a business unit of the Siemens Industry Automation Division, is a world-leading provider of product lifecycle management (PLM) software, systems and services with nine million licensed seats and 77,000 customers worldwide. Headquartered in Plano, Texas, Siemens PLM Software helps thousands of companies make great products by optimizing their lifecycle processes, from planning and development through manufacturing and support. Our HD-PLM vision is to give everyone involved in making a product the information they need, when they need it, to make the smartest decision. For more information on Siemens PLM Software products and services, visit www.siemens.com/plm.

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