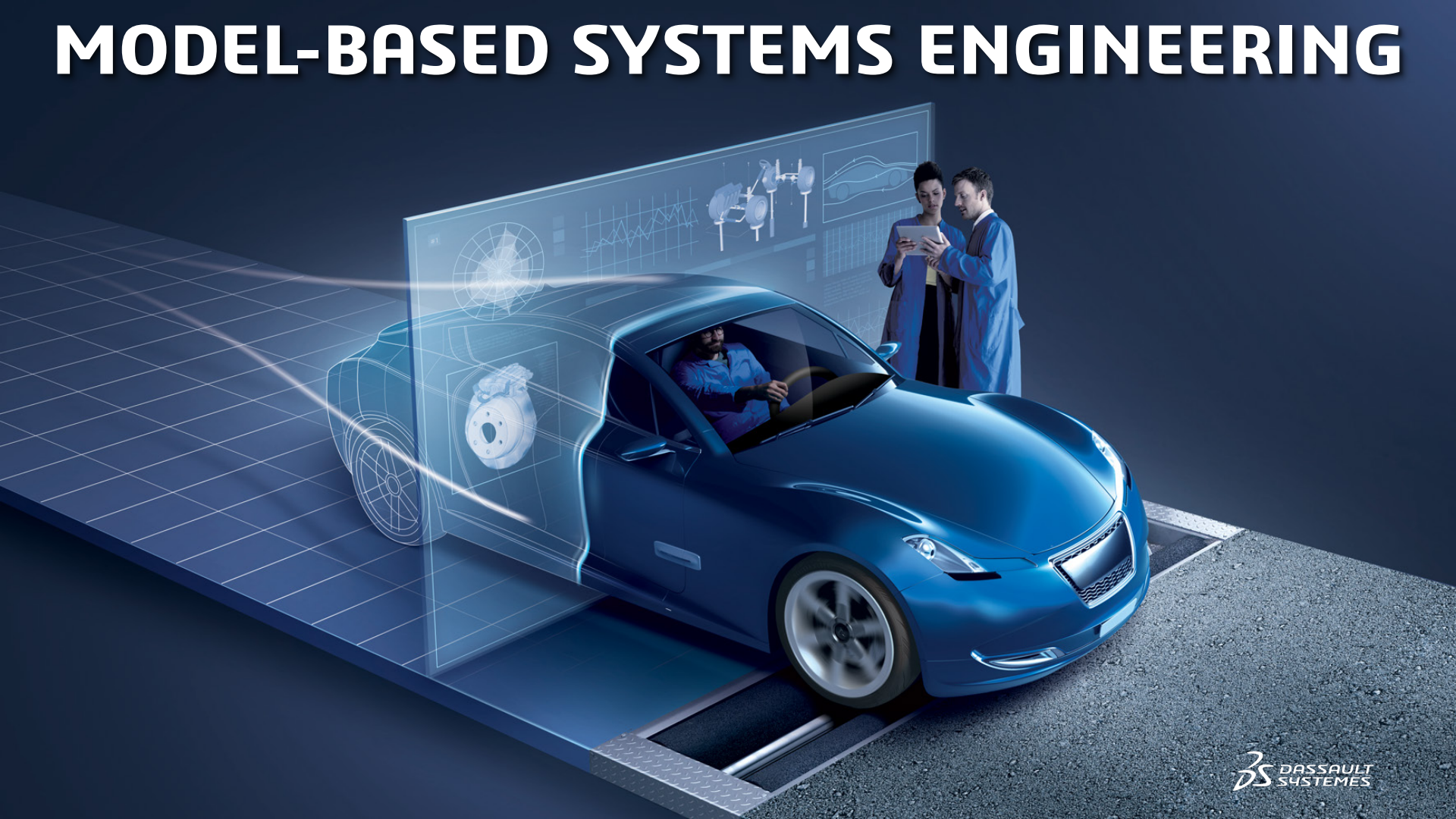
MODEL-BASED SYSTEMS ENGINEERING



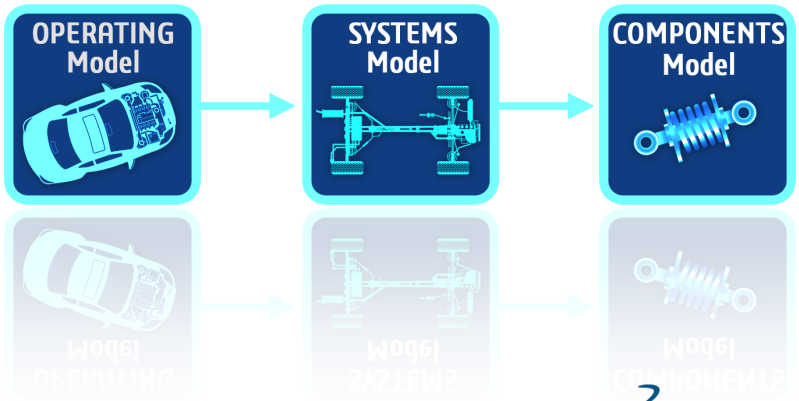
INTRODUCTION

In the 20th century, systems engineering methodology was developed so that a system could be decomposed into multiple sub-systems and each sub-system could be independently engineered, manufactured and serviced. The emphasis was laid on defining requirement specifications such that the sub-systems and its interactions with other sub-systems were clearly defined. This method emphasized upfront planning, analysis and specification. Hence, the term Requirements Driven Systems Engineering. In practice, it was always very difficult to specify upfront with a high level of accuracy and to resist changes to specifications during development. By and large this methodology has been inadequate and has led to delayed programs and last minute surprises; commonly referred to as the requirements-delay-surprise factor!

In the 21st century, iterative modeling and simulation play a crucial role in systems engineering. An operational model is first developed to understand all usage conditions, including the surrounding environment; then systems models are built and simulated; finally, component models are developed.

Change is integral to this methodology and requirements, structure, and behavior are derived and finalized with the help of the models. In short, the model as the master!

The fidelity of the models is continuously improved during the development and it is possible to combine models and physical systems, also called, Hardware in the Loop (HiL). When the physical systems are assembled, they are just a twin of the model. Tests conducted on this physical prototype can be continuously correlated against predicted behavior and be used to improve the fidelity of models.



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MODELS ARE EVERYWHERE

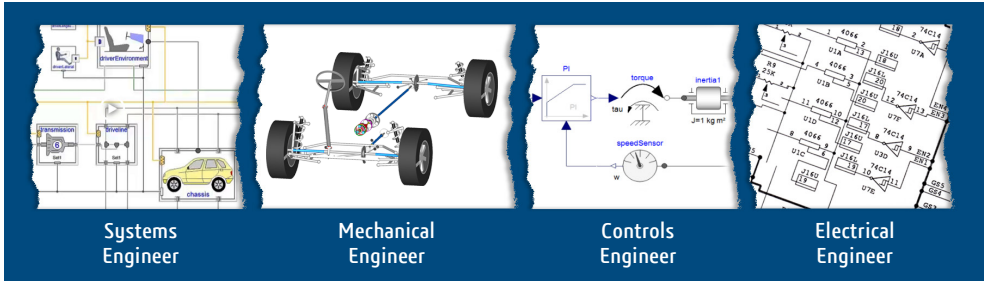
It's fairly common today for mechanical engineers to develop CAD models and subject them to structural, fluid and thermal simulation. Similarly, a number of models are built by engineers from other disciplines: software engineers use models to specify the operating conditions and interactions between systems; control systems developers build block-based models and generate software code for controllers; electrical engineers develop schematics and layouts of their design; electronics engineers develop high level logic that is synthesized into physical design; hydraulic engineers define hydraulic circuits. When interdisciplinary work is critical, multiple domains are combined. For example, the thermal and fluid dynamics models are simulated together to understand the performance of the climate control systems.

Systems integration nightmare. Since each discipline is working on their own models, most often the first time the engineers witness how the systems function together is when they finally assemble a physical prototype. Its not uncommon that the physical prototypes require numerous build, test, fix iterations, before they work as intended. The net effect: projects are delayed and quality suffers.

The era of autonomous systems. New types of sensors, complex control algorithms and the integration of on- and off-board systems are the drivers of autonomous capabilities. This leads to an increase in software-based functionality and E/E complexity never seen before.

Coupled with ever-shorter time to market demands, it can become the perfect storm if complexity is not mastered starting from the early phases of product definition.

Even though models are used by every engineer, they are siloed by discipline, requiring physical prototypes for integration and validation.



WHAT IF... Engineers from all the disciplines could work together on a multi-disciplinary virtual prototype and simulate how the product works before building a physical prototype?

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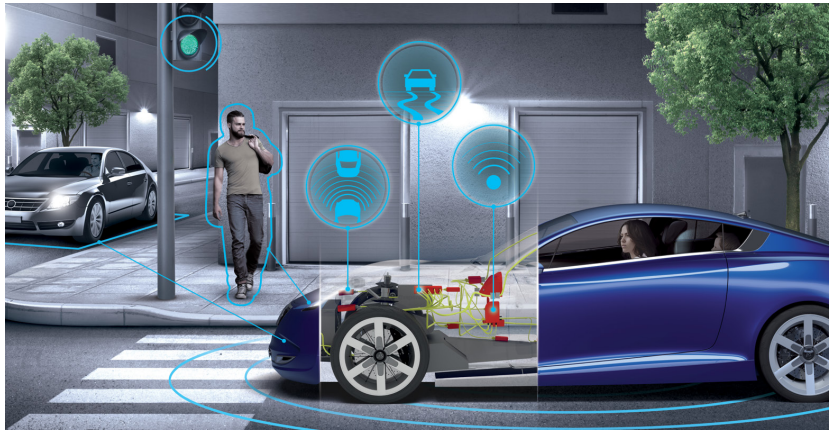
SMART, SAFE AND CONNECTED

Design, validate, deliver the intelligent vehicle experience



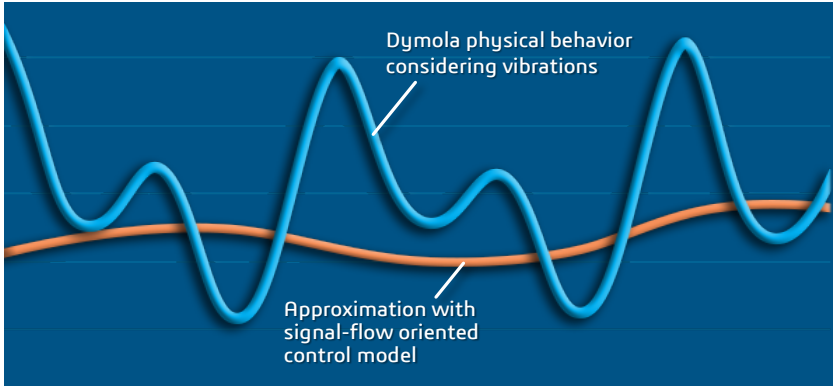
Smart, Safe and Connected Industry Solution Experience based on the **3D**EXPERIENCE® platform connects mechanical, embedded electronics and software development teams on an end-to-end digital platform and enables them to build a multi-disciplinary virtual prototype right from the early stages of concept design.

Engineers can rapidly model and test their ideas in various operating conditions before proceeding with detailed design. They can simulate the way multi-disciplinary features interact, enabling early detection of potential conflicts, if discovered at a later stage, could delay projects and drive up costs. This improves stakeholders' agility and ability to rapidly choose concepts that improve safety and comfort.

Dymola® dynamic physical systems modeling and simulation capability is part of this purpose-built solution for developing smart, safe and connected vehicles.

Make your vehicle models dynamics capable. If you are currently building control systems models in a signal-flow oriented tool, higher fidelity and more accurate control can be achieved by incorporating simulation of dynamic physical systems with Dymola.

Signal-flow oriented control models typically don't fully incorporate dynamic effects caused by road, driving conditions and suspension design. These affect driving comfort and safety, and if not incorporated in the models, may lead to issues discovered only later during physical testing. Simulating dynamic behavior under various road and driving conditions helps identify and fix issues in the early phases of product development.



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DYNAMIC SYSTEMS MODELING AND SIMULATION

The design and engineering of autonomous systems requires a new model-based systems approach – it needs to be multi-disciplinary from the get go! Dymola and the VeSyMA libraries are a capitalization of decades of experience with dynamic systems modeling.

Dymola is a physical modeling and simulation environment, for model-based design of dynamic systems. Dymola adopts the Modelica language and is accompanied by a portfolio of multi-disciplinary libraries covering the mechanical, electrical, control, thermal, pneumatic, hydraulic, powertrain, thermodynamics, vehicle dynamics and air-conditioning domains. Library component models are coupled together to form a single complete model of the system. You can extend existing models or create custom models, improving reuse across projects.

Vehicle Systems Modeling and Analysis (VeSyMA®) is a complete set of libraries for vehicle modeling and simulation. It includes engine, powertrain, suspensions libraries that work in conjunction with the Modelica® Standard Library. In addition, battery with electrified and hybrid powertrain libraries are available as well.

Model Import and Export. You can import models directly from Simulink® into Dymola. Dymola also supports the FMI® Standard 1.0 and 2.0 for both model exchange and co-simulation.

Real-time Simulation. Dymola supports real-time code generation for simulation on a wide range of HiL platforms from dSPACE®. Dymola generated code has been tested and verified for compatibility with multiple combinations of dSPACE and MATLAB® releases.

Driver-in-the-Loop Simulation. Dassault Systèmes' partner, Claytex, integrates Dymola with driving simulation software. Libraries built by Claytex include a car template and support for LiDAR, radar and ultra-sound sensor libraries that work with the simulator. Before exporting the model, simulation can be run in a test environment within Dymola as well.

Systems modeling case-study: Energy management of trucks at Arrival. www.arrival.com
Source: *energy**engineering** magazine. Low Carbon Vehicle special edition – Autumn 2016*

The electrification of trucks involves efficient energy management and also needs to maintain the vehicle attributes at the same level as a conventional powertrain system. Hence, it requires detailed studies of vehicle system interactions in order to understand the vehicle system that dominates these attributes. The upfront modeling approach is vital to capture these attributes before developing the physical prototype.

Dymola has a multi-physics modeling capability that is very useful in developing these complex interactions at both vehicle system level and sub-system level, and for pin-pointing the dominant systems or components. All of these vehicle systems/subsystems can be modeled within the same modeling workspace at the top level and then cascaded to a lower level in order to create a series of libraries that can be repeatedly used for different vehicle plant model architectures. This process is important for system modeling, particularly during development phase, giving engineers access to different options to optimize the system architecture for energy management and the improvement of other vehicle attributes. The process minimizes the design and product risks by not committing tooling costs for the prototype build, as the majority of the validation activities can be simulated to produce results that are a close representation of the physical system/sub-system components, which also reduces the development lead-time. Another advantage of system modeling is being able to perform component sizing optimization for energy management in order to improve the vehicle range.

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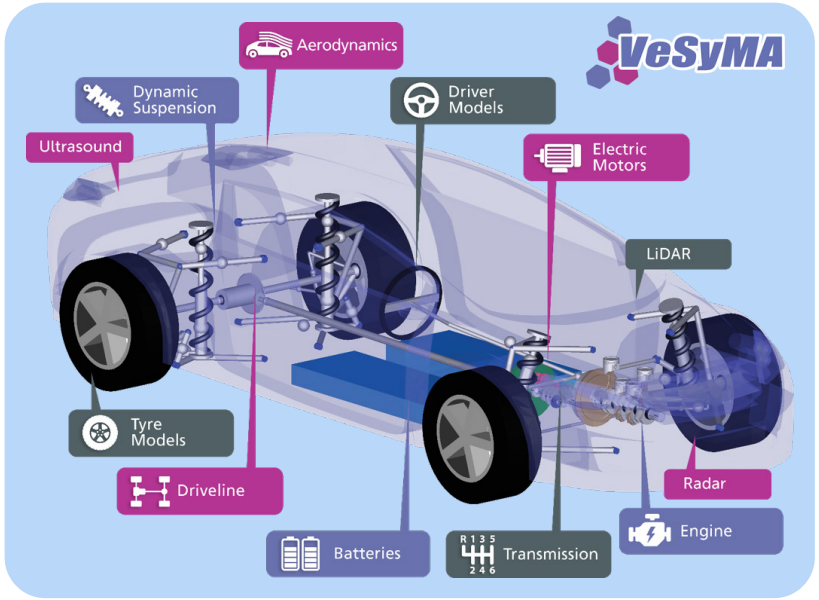
DYNAMIC SYSTEMS SIMULATION WITH DRIVER IN THE LOOP

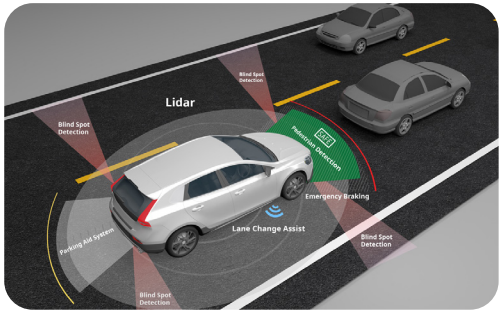


DYMOLA Systems Engineering

- Build dynamic physical systems models and simulate them using Dymola
- Import and export models between Simulink and Dymola
- Import FMI models or co-simulate with the FMI interface

VeSyMA

Vehicle Systems Modeling and Analysis (VeSyMA) is a complete set of libraries for vehicle simulation



Driver-in-the-Loop Simulation

Interface with and directly run the vehicle model as part of a driver-in-the-loop simulation

"Dymola has a multi-physics modeling capability that is very useful in developing these complex interactions at both vehicle system level and sub-system level, and for pinpointing the dominant systems or components. All of these vehicle systems/subsystems can be modeled within the same modeling workspace at the top level and then cascaded to a lower level in order to create a series of libraries that can be repeatedly used for different vehicle plant model architectures."

Dr. Raja Mazuir Bin Raja Ahsan Shah, **Arrival** - The Smart Electric Van

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DYNAMIC PHYSICAL SYSTEMS MODELING – A Checklist

If you are want to incorporate dynamic behavior into you vehicle models, the following are some of the key capabilities of the modeling environment that you may want to consider.

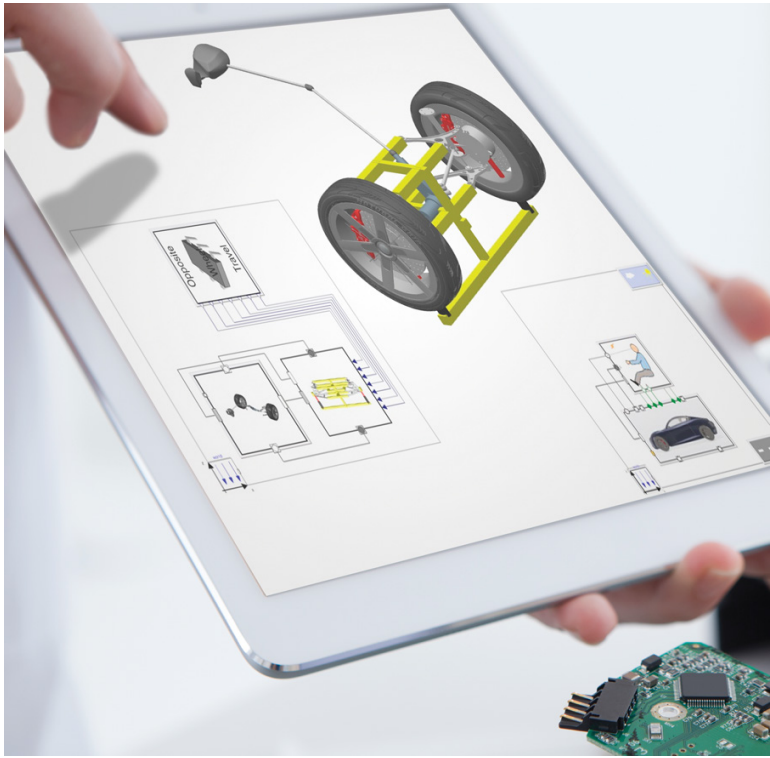
Breadth of Library Models: Are there pre-built libraries for the sub-systems that are included in your system? If your systems are multi-disciplinary in nature, look for libraries across multiple domains containing models for mechanical, electrical, control, thermal, pneumatic, hydraulic, power train, thermodynamics, vehicle dynamics, air conditioning, etc.

Object Oriented: Can you directly instantiate the library models and build your systems with ease? Typically, look for a drag and drop interface. Also, look for the ability to abstract sub-systems in a single model. If necessary can you modify the library models and create your own derivatives of the models? Model management capabilities are a key requirement if you are working in a team.

Equation Based. Can the dynamic behavior of systems be described by differential and algebraic equations? Does it support the concept of *flow* and *across* variables?

Acausal. Does the environment support the definition of equations in a declarative form, without considering the sequence? This reduces the effort to describe behavior in comparison with procedural languages like C and other block-based tools, where signal flow direction needs to be considered.

For a review of Dymola capabilities, please click here.



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The 3DEXPERIENCE® Company

Articles in the series:

Model-based Systems Engineering – A Primer

Dynamic Vehicle Behavior Simulation – A Deep Dive

System Architecture with SysML for Control Systems Engineers