NORDIC 2010 NAFEMS CONFERENCE

Model Based Engineering of Intelligent Vehicles

Peter Mas

LMS International

NORDIC 2010 NAFEMS CONFERENCE

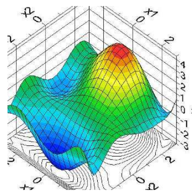
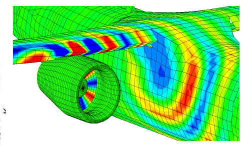
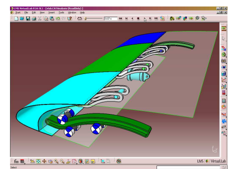
Agenda

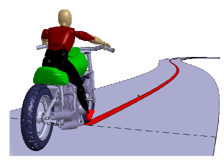
- Status on virtual Engineering
- Drivers for automotive Industry
- Towards “model based system engineering”
- Examples of “model based system engineering”
- Conclusions and what is “next”

Introduction: Virtual Engineering

Cornerstone of modern design engineering

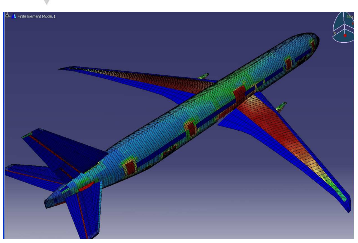
- **Performance prediction before a prototype is available**
  - Design Verification
  - Parameter Influences
  - Design Space Exploration
  - Design Parameter Optimization
  - Uncertainty Assessment
- **Wide Range of Performances**
  - Power
  - Energy Consumption
  - Handling & drive-ability
  - Strength & Durability
  - Noise and Vibration
  - Safety
  - Thermal & Comfort



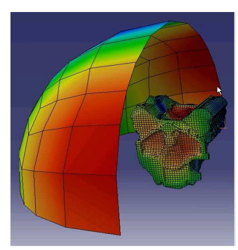
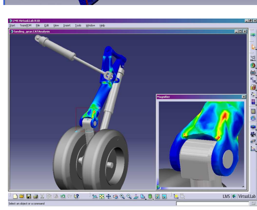
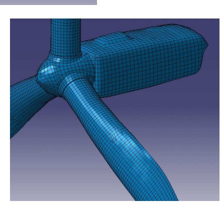
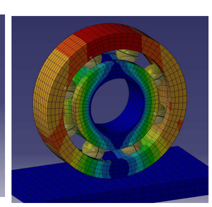
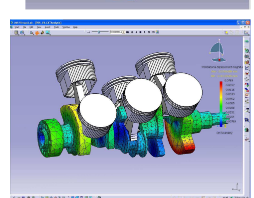
Introduction: Virtual Engineering

Cornerstone of modern design engineering



Next challenges

- Larger models?
- Higher frequencies?
- More complex models?
- System level models?
- Micro to macro scale

What are the demands for a “Next” generation development process To support the modern product design challenge?

Agenda

- Status on virtual Engineering
- **Drivers for automotive Industry**
- Towards “model based system engineering”
- Examples of “model based system engineering”
- Conclusions and what is “next”

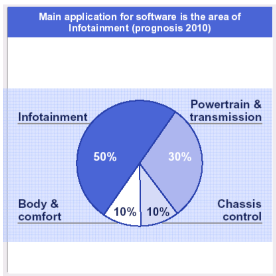
Defining the product innovation agenda

Product Innovation

Process Innovation

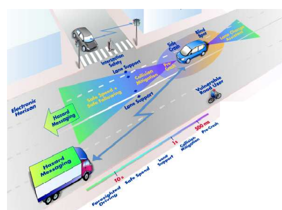
Brand values		Creating unique brand values and customer experiences
Sustainable Environment		Responding to Eco trends, e.g. fuel and energy efficiency, more stringent regulations for safety and environment
“Smart Systems”		Mastering integration of technological advance in materials, nanotechnologies, controls, mechatronics… *“80% of product innovation will be software-driven or electronics-based”* *McKinsey*
Process efficiency & productivity		Managing a continuous renewal and expansion of the product portfolio to capture changing market needs

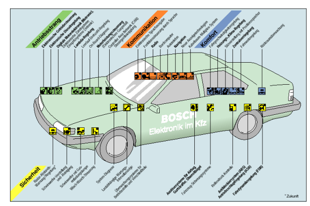
Smart systems driving innovation



Source : Arthur D. Little surveys and analysis

- Electrical & electronic content in the vehicle value is increasing to over 40%
- Up to 80% of future innovations will be based on the use of some form of "intelligent systems"
- Focus area's: chassis, body and powertrain:
  - Performance and Comfort -> power, brand, drivability, noise….
  - Economy and Green Driving
  - Safe driving -> ABS, ESP, VDC, ADAS, V2V…



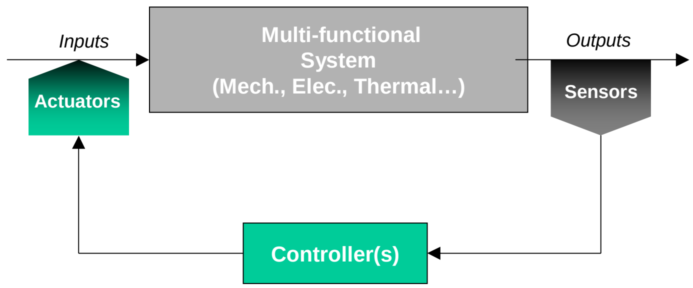


Agenda

- Status on virtual Engineering
- Drivers for automotive Industry
- Towards "model based system engineering"
- Examples of "model based system engineering"
- Conclusions and what is "next"

Intelligent vehicle system concepts

- Building blocks of intelligent systems

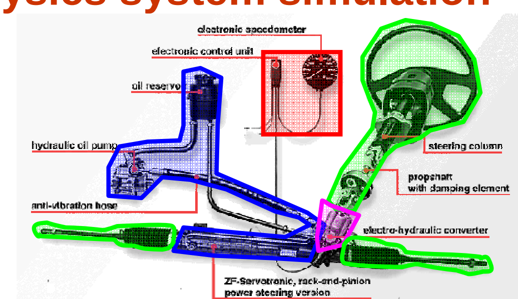


- Key elements
  - “Plant” System part -> mechanical (structural kinematic, hydraulic…), electrical, electronic systems
  - Control System part -> hardware, software
  - Interconnection with other systems

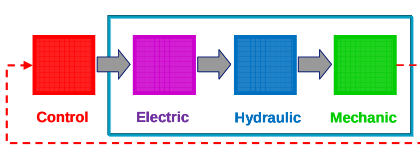
Multi-Physics system simulation

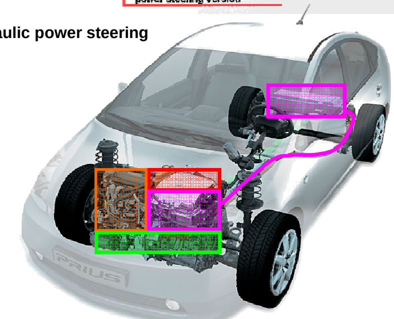
- Definition: a **System** is a group of independent but interrelated elements comprising a unified whole needed to accomplish a function or set of functions

- Any system is **multi domain or multi-physics**:
  - **Control**
  - **Electric**
  - **Hydraulic**
  - **Mechanic**



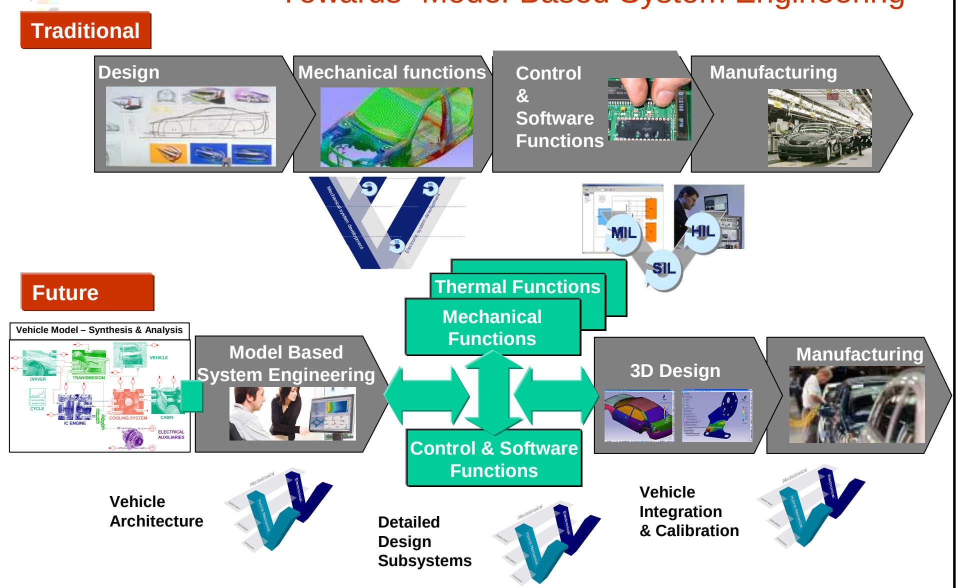
Ex: Electro-hydraulic power steering





Ex: Toyota Prius

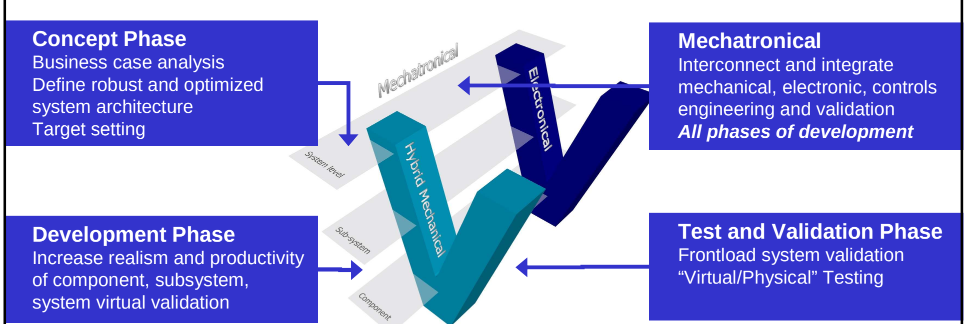
Re-thinking product development
Towards “Model-Based System Engineering”



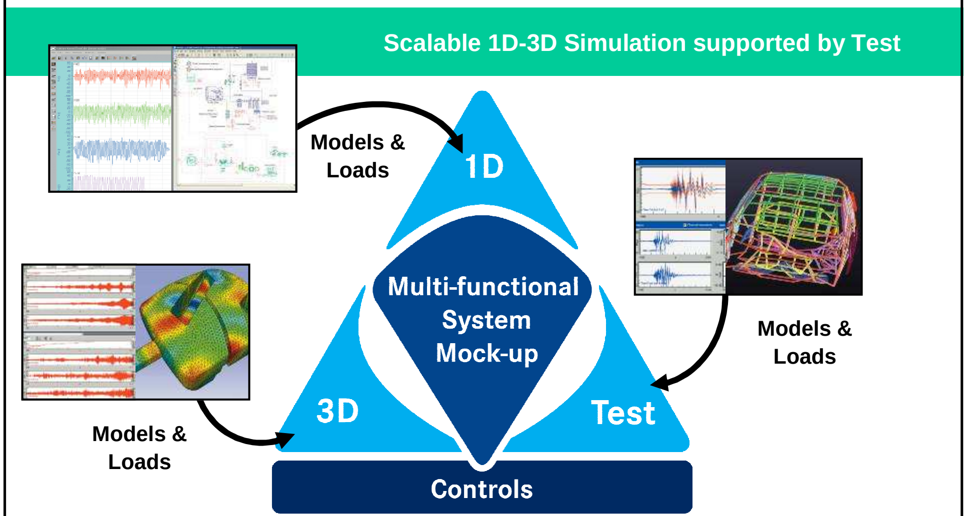
Model Based System Engineering
The Next Frontier in Simulation

Implement *System Level Simulation* in all phases of development

- **System architecture** is put **central** – from requirements to test
- **Multi-disciplinary models** for component, subsystems, systems
- **“Model Based” paradigm** is shared with **Controls Engineering**



Multiphysics System-level Simulation
Multi-Functional System Mock-Up

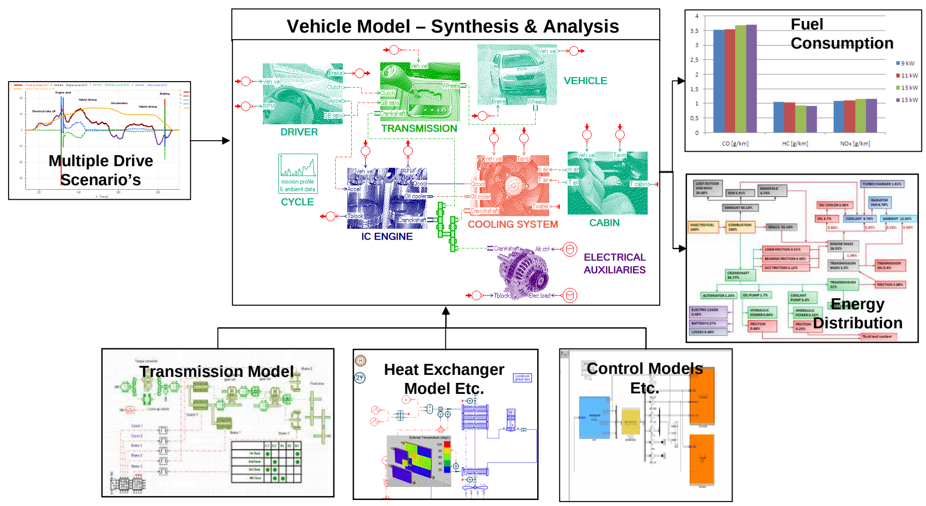


Agenda

- Status on virtual Engineering
- Drivers for automotive Industry
- Towards “model based system engineering”
- Examples of “model based system engineering”
- Conclusions and what is “next”

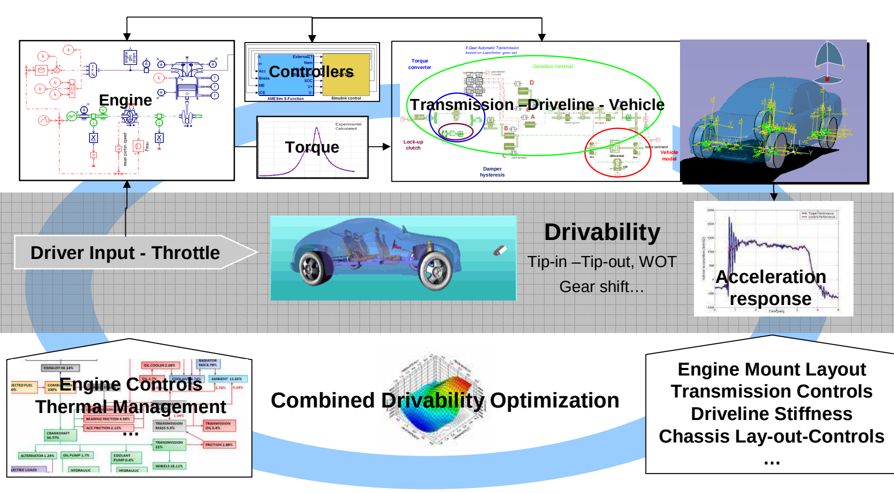
System Architecture Engineering

Example: Vehicle Energy Management simulator



System Architecture Engineering

Drivability optimization of vehicles (HEV)

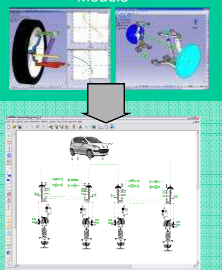


Source: "Development of High-Fidelity Combustion Driven Vehicle Models for Driveability Using Advanced Multi-Body Simulations", JSAE 2007-1-1634
K. Gotoh, TOYOTA, R. Yakoub, LMS

Scalable 1D/3D CAE in different stages

Example: vehicle dynamics engineering

Component – Subsystem Models



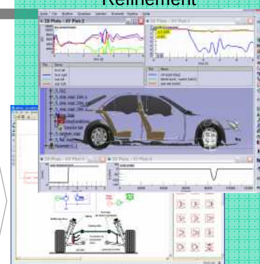
Ride & Handling

1D Simulation
Chassis Concept

Suspension type
Hard points
Bushing, damper settings

Increasing Design Details

Component – Subsystem Refinement

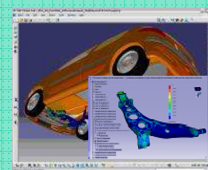


Ride & Handling - Comfort

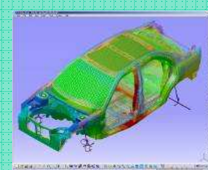
3D Simulation
Chassis Detail – Body Concept

Details subframes – incl. flexibility
Body concept model - incl. flexibility
Tire models

Increasing Design Details



Loads for component durability analysis



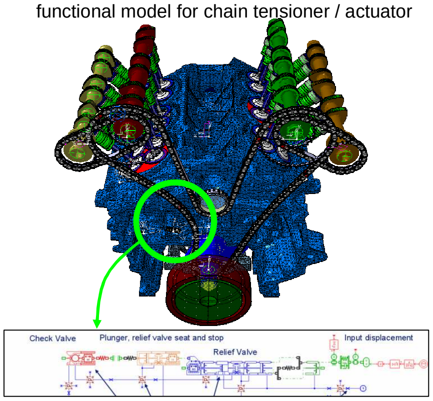
Road Noise

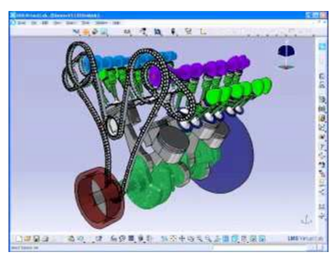
Realistic system simulation

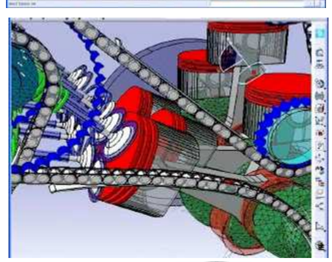
Enabled by combining 1D and 3D simulation technologies

Example: Simulation of chain whine

1. Fully coupled 3D mechanical model
   Upper& Lower Engine - MBD – FEM
2. Coupled 1D – 3D simulation with
   functional model for chain tensioner / actuator





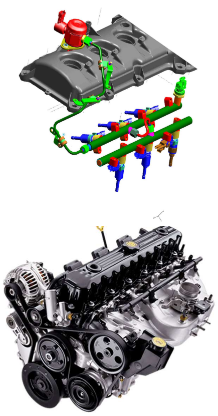


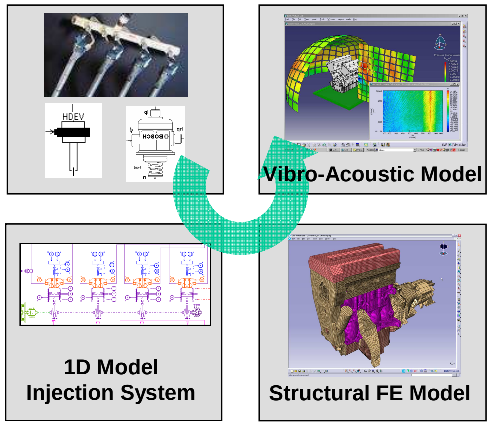
Source: "Utilization of CAE/Hybrid methods as an enabler of up-front design optimization"
Takeshi Abe, FORD
2007 LMS Conference on Virtual and Physical Prototyping

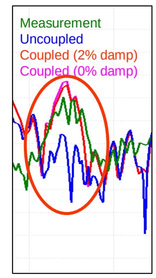
Realistic system simulation

Enabled by combining 1D and 3D simulation technologies

Example: Simulation of high frequency impulsive noise (Direct Injection) in high efficient Internal Combustion Engine (ICE)







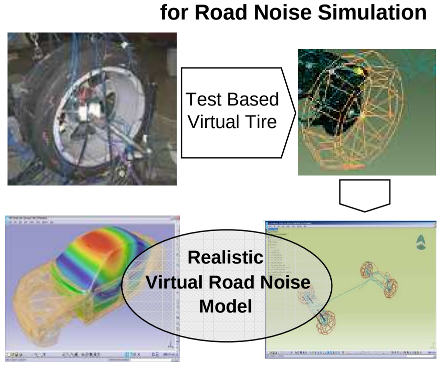
Source: "Driving NVH Refinement of Next Generation Powertrains through Virtual Design", Mario Felice, FORD
2008 LMS Conference on Virtual and Physical Prototyping

Improving "realism" and "productivity"

Based on combined use of Test and Simulation

Realistic Simulation

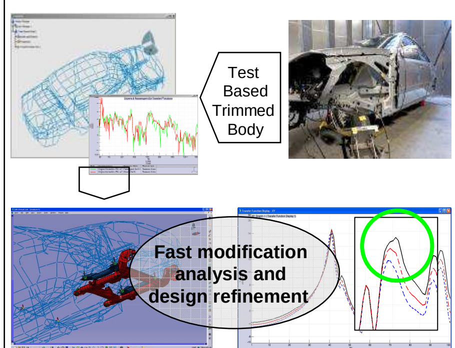
Example: Test Based Tire Model for Road Noise Simulation



Vehicle Dynamics Model for Road Noise

Accelerated Simulation

Example: Test Based Trimmed Body Model

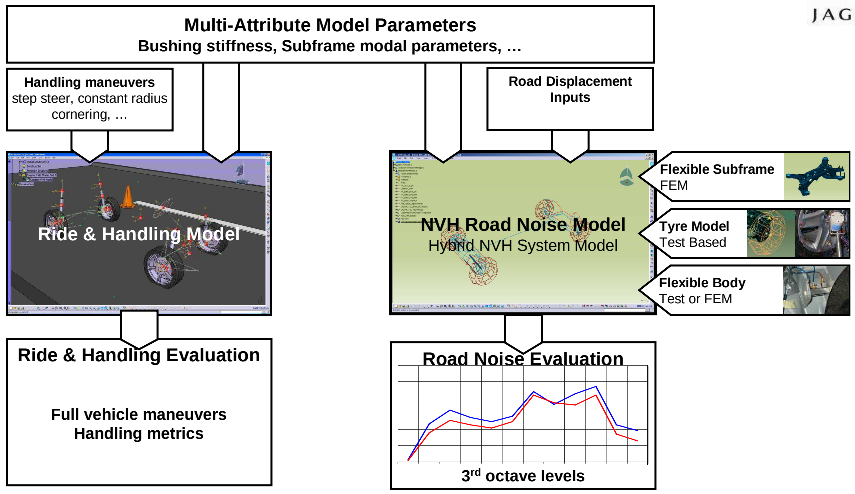


Test – CAE Substructuring

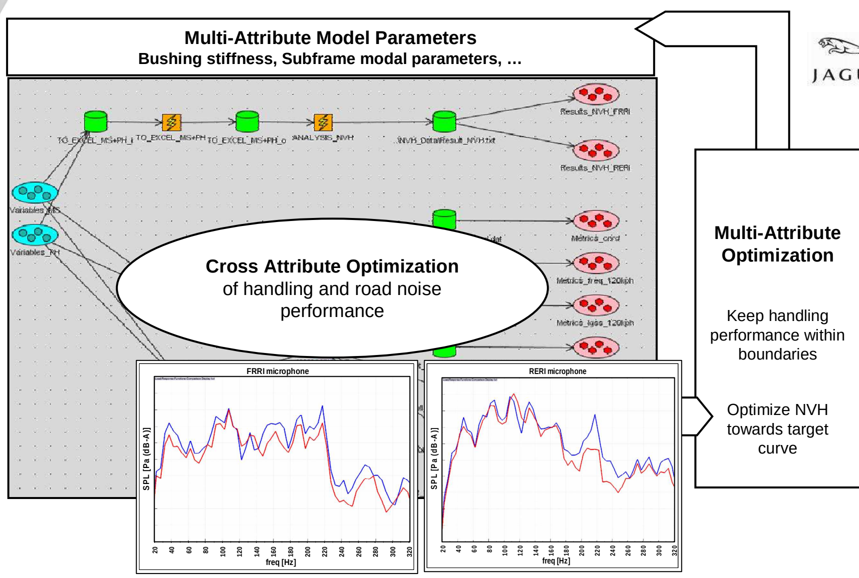
Measurement and analysis innovation – in support of simulation

Frontloading compromising of conflicting system attributes

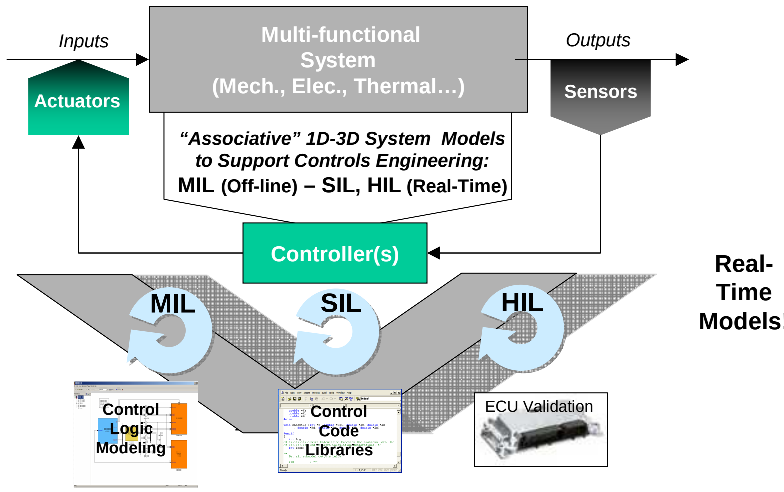
Example: Ride & Handling and Road Noise



Frontloading compromising of conflicting system attributes



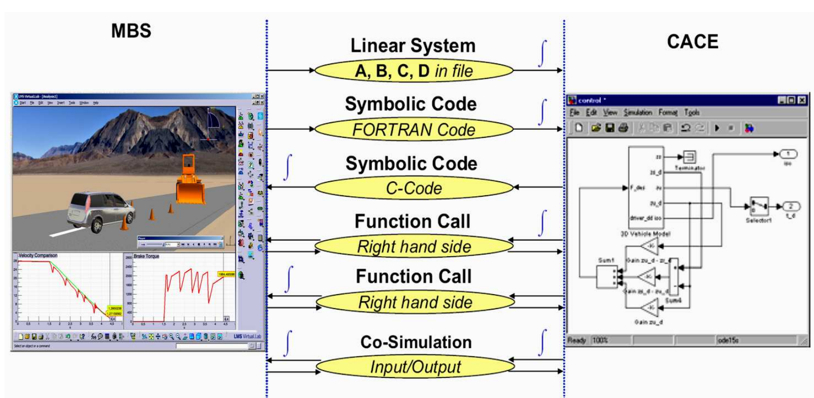
Interoperability between System and Control Modeling



Associative 1D-3D system models
to interconnect mechanical and electronics/control engineering

Interoperability between System and Control Modeling

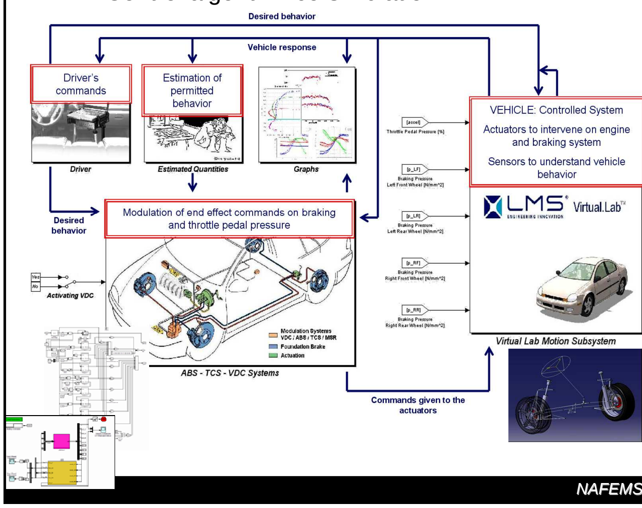
- Add the control dimension to the Multi-functional System Mockup
  - Embedding equations
  - Co-simulation



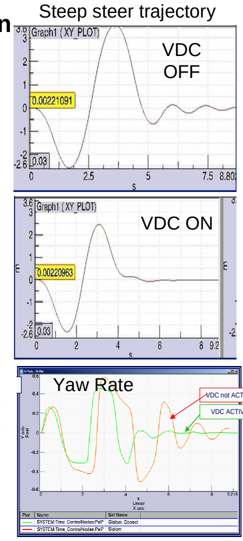
NAFEMS NORDIC REGIONAL CONFERENCE 2010

Interoperability between System and Control Modeling

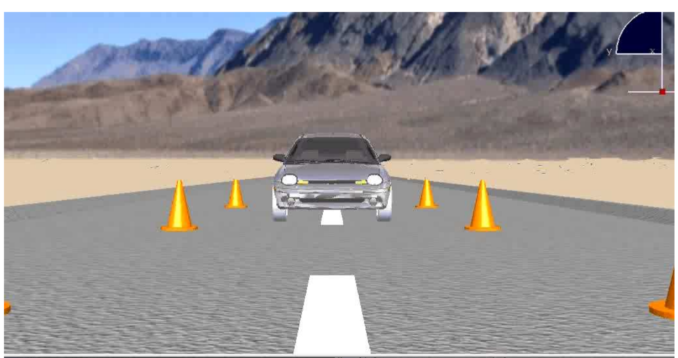
- **Example: Vehicle Dynamics Control system co-simulation**
  - 3D MBS model of suspension, 1D model for ABS
  - Control algorithm co-simulation

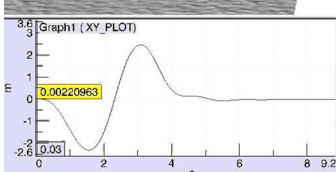


Steep steer trajectory

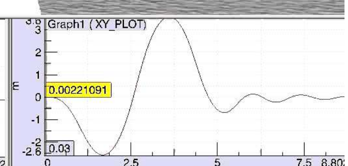


Vehicle dynamics for active safety





VDC system ACTIVE

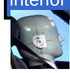


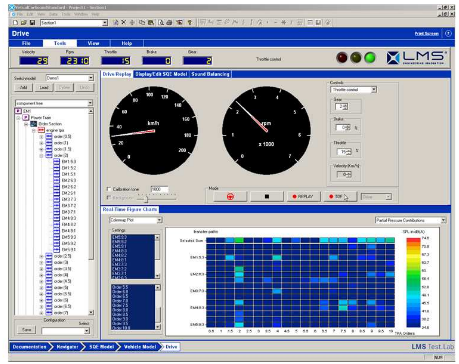
VDC System NON active

Human Perception relevant Simulation

Virtual Car Sound Model

- interior noise
  - powertrain
    - orders: A,Ph = f(Rpm,th)
    - background noise third octave bands: A = f(Rpm,th)
  - road - tire
    - third octave bands: L = f(speed)
  - wind
    - third octave bands: L = f(speed)





- Evaluation of sound perception
- Creation of sound targets
- Model based sound optimization

Model Based System Engineering

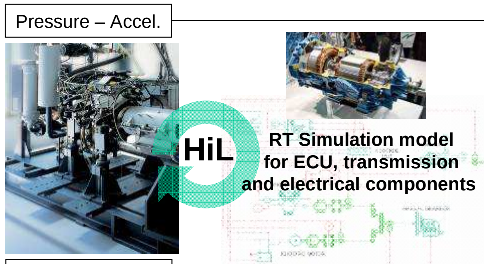
to frontloading physical testing and validation

- **Simulate on the test cell the "working" of target build-in environment**
- **Process and analyze test cell data in context of target build-in environment**

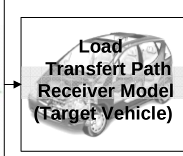
Example: Hybrid Powertrain Development

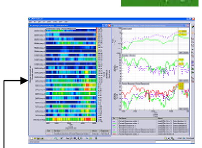
Testing and calibration of ICE to be used in hybrid powertrain

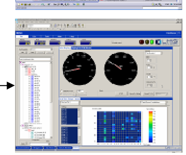
Pressure – Accel.



Pressure – Accel.



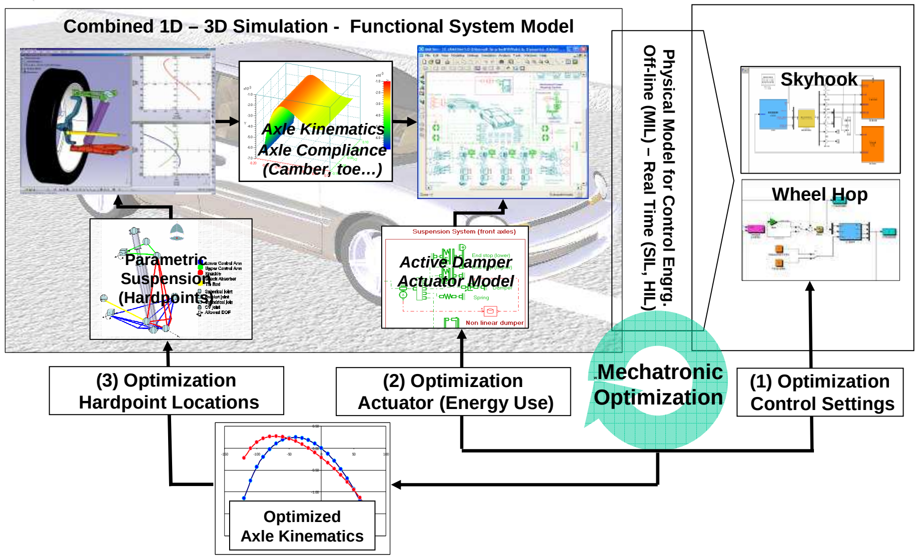




Simulation is key to enable frontloading of testing and validation

Example: Active Suspension Design

Joint performance and energy optimization

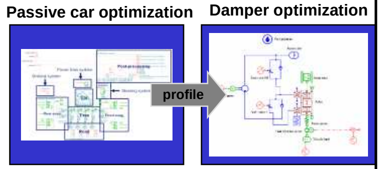


Example: Active Suspension Design

Joint performance and energy optimization

- Model based development: engineering and real time models of vehicle and shock absorber
- Development of State estimator improves damper force accuracy from 30% to 5% resulting in higher performance control
- 50% less power consumption after optimization
- Prototype vehicle results
- Target integration from C-class upwards

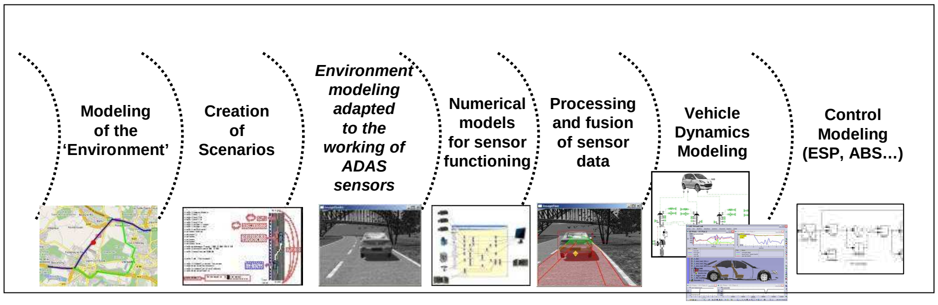
Passive car optimization | Damper optimization



MBSE for Active Safety

Challenges in developing solutions for ADAS development

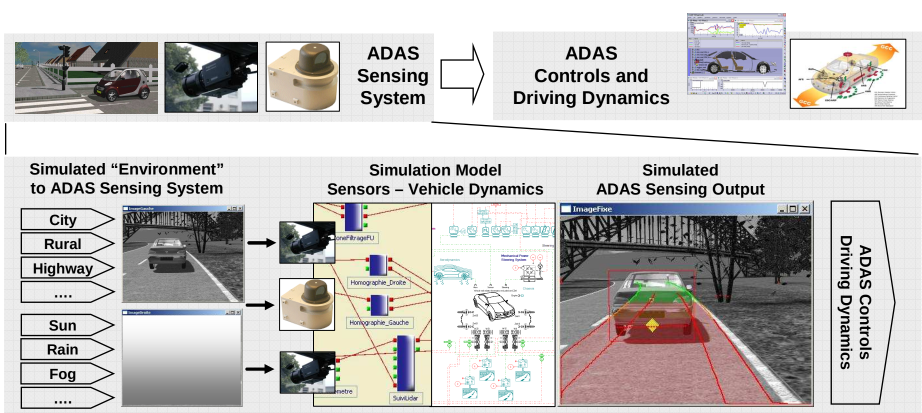
- Virtual Environment Monitoring Simulator
- To support Virtual Design, Prototyping and Validation of ADAS
- Sensor modeling, infrastructure modeling and scenario creation



- Virtual scenario validation
- Test scenario selection
- Operational Field Testing

MBSE for Active Safety

Challenges in developing solutions for ADAS development



Accelerating development of ADAS sensing systems by frontloading millions of test driving into model based simulation

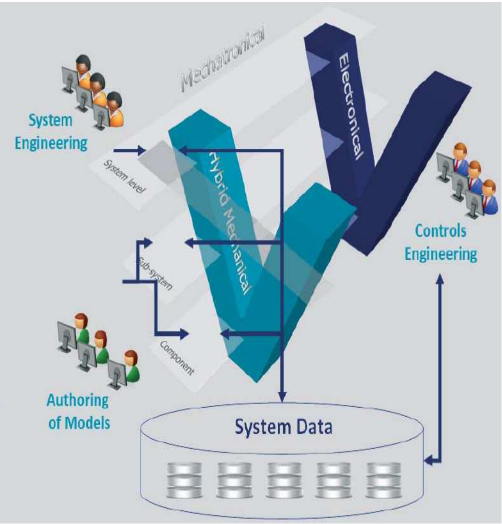
And how to manage your data

ORGANIZE
Apply a user defined information model
to organize system data and models

CONTROL
Implement "version" and "variant" management
for full data and models traceability

SHARE
Implement collaboration workflows
with role based access control

USE & CAPITALIZE
Put your resources and know-how to work for more
effective and efficient product development

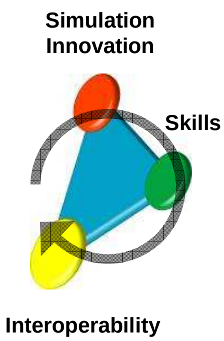


Agenda

- Status on virtual Engineering
- Drivers for automotive Industry
- Towards "model based system engineering"
- Examples of "model based system engineering"
- Conclusions and what is "next"

Model Based System Engineering

Making mechatronic optimization of smart products work



System Simulation Innovation

- <u>In different technology domains</u> – 3D, 1D, Test
- <u>Simulation System Models</u> that include <u>multiple physics</u>
- <u>Co-simulation frameworks</u> (Spatial and Time)
- Simulation models - both <u>High-fidelity AND Real-Time</u> to <u>support controls engineering</u> and <u>mechatronic system engineering</u>

Skills:

- To be able to <u>work at the intersection of multiple simulation disciplines</u>

Interoperability

- Room for <u>standards</u>…: System Modeling Languages, Co-simulation frameworks, Data / Model exchange
- …making <u>"Co-opetition" [1] work</u>

[1] Co-opetition - cooperation between partners that are also competitors
Ray Noorda, CEO Novell, 1994

Multi-functional System Mock-up

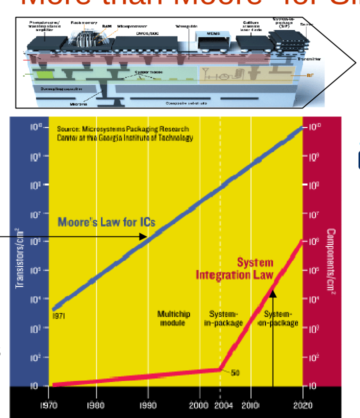
"More Moore" and "More than Moore" for Simulation

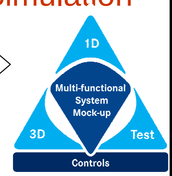
Analogy with "Moore's Law"

1D, 3D, Test – Functional Domain

- Continuous innovation in algorithms
- Progress in computing (*Multi-CPU, Grid computing)*

"More Moore"





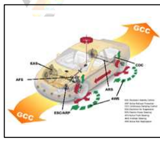
Model Based System Engineering

- Combined & heterogeneous solutions *1D-3D Simulation, Simulation -Test*
- Integration with Control

"More than Moore"

"More Moore" and "More than Moore"
to impact of (system) simulation in all phases of development process

Conclusions



"80% of product innovation will be software-driven or electronics-based"

Source: McKinsey

"More than 50% of defects and warranty costs"

"Close to 70% of large electronics integration projects face major problems"

Source: A.D. Little

- Development of "Smart Products" mandates re-thinking the ***Product Development Process towards "Model-Driven Development"***
- "Model-Driven Development" requires innovation to increase the impact of ***System Level Simulation – in all phases of development***
- ***Enabled by a Model Based System Engineering approach***
  - **System architecture** is put **central** – from requirements to test
  - **Multi-disciplinary models** for components, subsystems, systems
  - **"Model Based"** paradigm is **shared with Controls Engineering**
- Making it work = ***Innovation in Simulation*** and Supporting Systems, Adapted ***Processes and Organization***, and ***Interoperability*** and ***Skills - Knowledgeable and Competent***