Simcenter Engineering Services for the Heavy Machinery and Off-highway Industry: Energy Management and Multi Attribute Balancing.

François IKER

Simcenter Nordics, Goteborg, May 2018

Impact of mega trends on construction and agricultural vehicles*

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Siemens PLM Engineering offering

Decreased demand for construction equipment in developed markets

- The construction market is mature, and has relatively fewer activities in progress.
- A transition to rebuilding and maintenance rather than infrastructure expansion is occurring, indicating a demand for smaller vehicles and equipment.

New product opportunity—hybrid heavy construction equipment

- Heavy-use, high duty-cycle heavy equipment demonstrating business case for hybrid power trains allows for smaller internal combustion engines than are normally associated with this equipment.

Rightsizing and downsizing

- Shift toward smaller engines expected, which provide the added benefit of offering greater visibility around equipment.
- Users are hobby farmers, small orchards, and vineyards using smaller tractors.

Growing regulations

- Trends toward stricter and greater regulations for noise and emissions from urban construction vehicles; in turn, this trend is expected to drive demand for low hp equipment. e.g. Tier IVi/Stage III

***Source: Frost & Sullivan 2013**

Outline

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- Simcenter Engineering Services introduction and approach

- Vehicle Energy management (VEM) and Multi attribute balancing

- Simcenter Engineering Services experience in off-higway and trucks

LMS Engineering applies the vision at the customer within the predictive engineering analytics offer of Simcenter™

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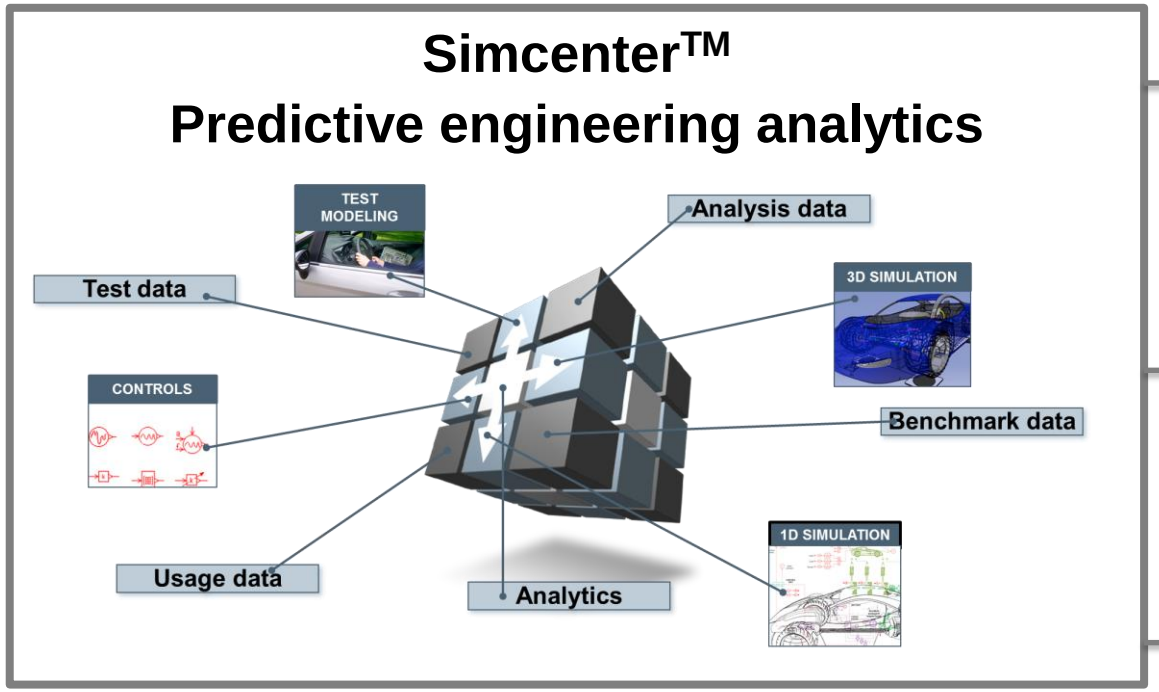

Application know-how

Technologies

Solutions for product improvement

LMS Engineering supports customers to:

- ✓ **Meet** their customer expectations with increased product performances
- ✓ **Solve** critical product challenges
- ✓ **Frontload** design choices
- ✓ **Reduce** time-to-market up to 30-50%
- ✓ **Reduce** weight and development cost

Simcenter Engineering Services – LMS & CD-adapco

Experience and global talent for valued customer partnerships

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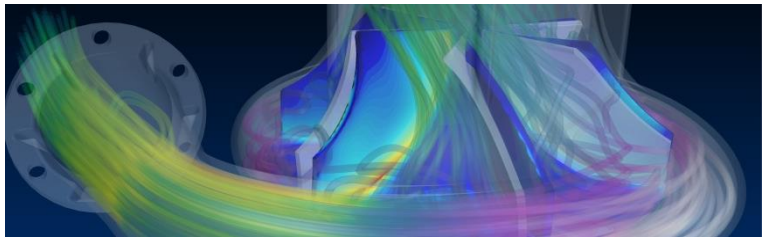
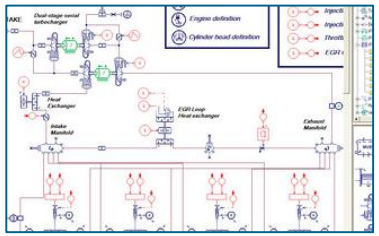
Troubleshooting

Co-development

Technology transfer

Engineering process transformation





Performance Engineering

Noise & Vibration

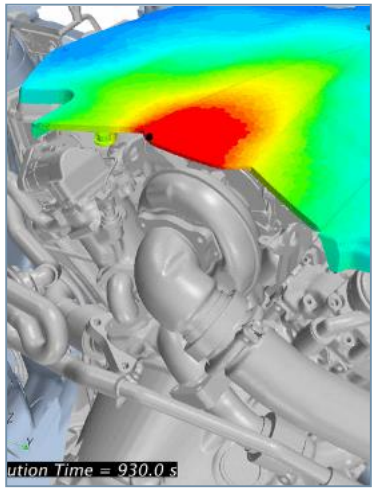
Durability

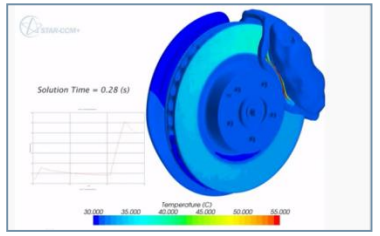
Fuel consumption

Mechatronics development

CFD

Combustion





Enable higher ROI at customers by combining Simcenter™ products with smart technologies and unique solutions of Simcenter Engineering Services

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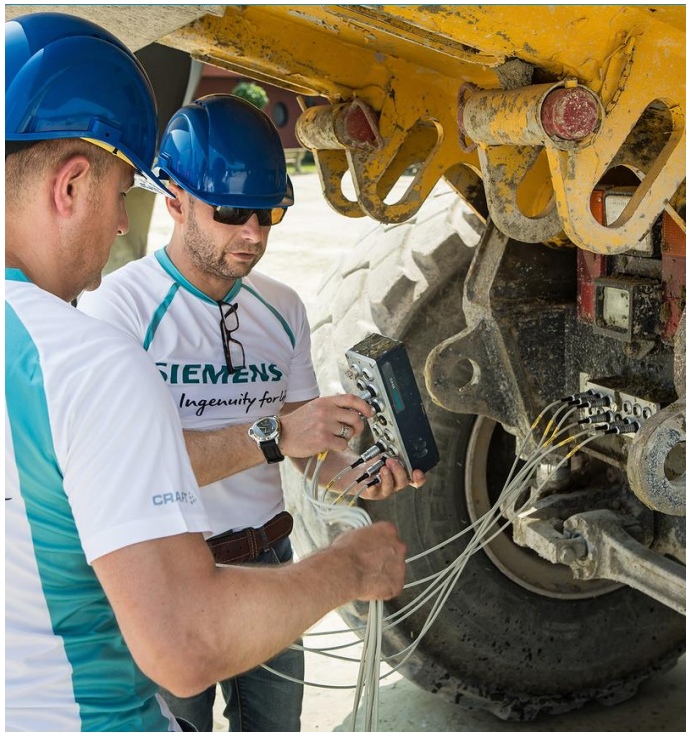
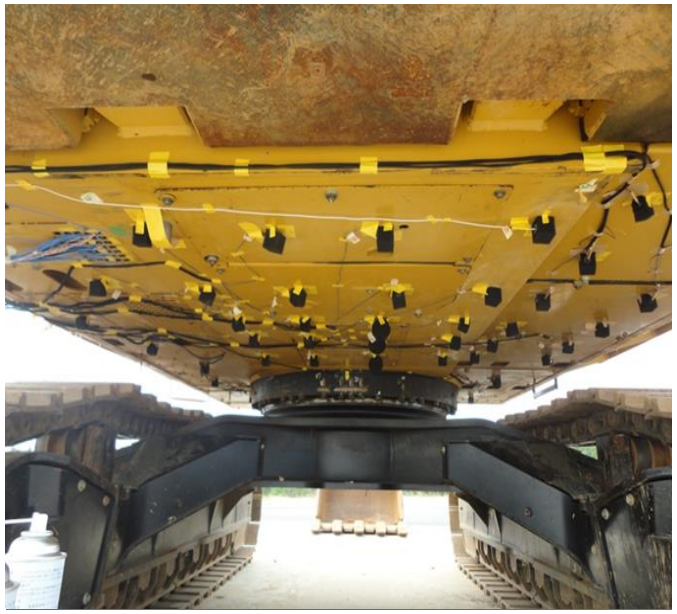
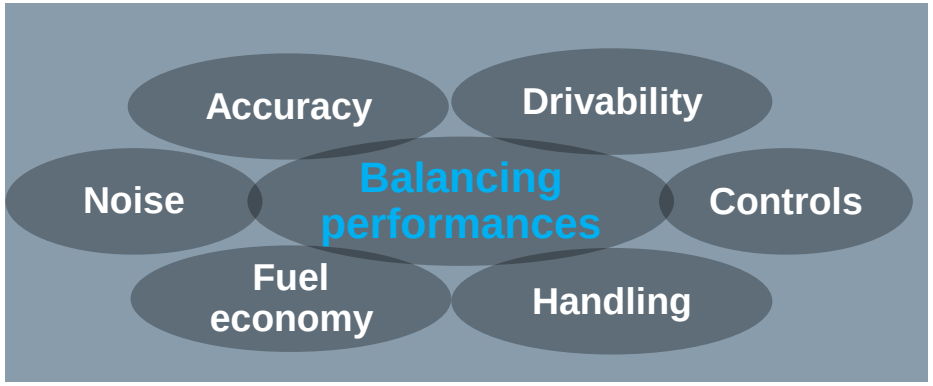
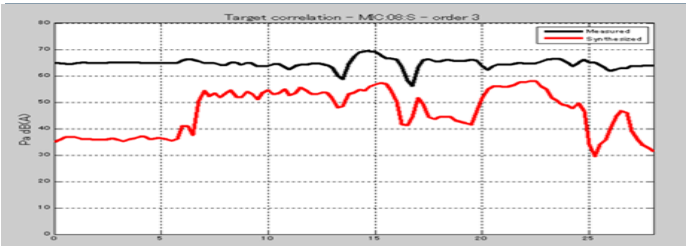
Integrate performance optimization in the full product development cycle





Simcenter™ Engineering Services





Simcenter Engineering Services

Smart technologies. Unique solutions.

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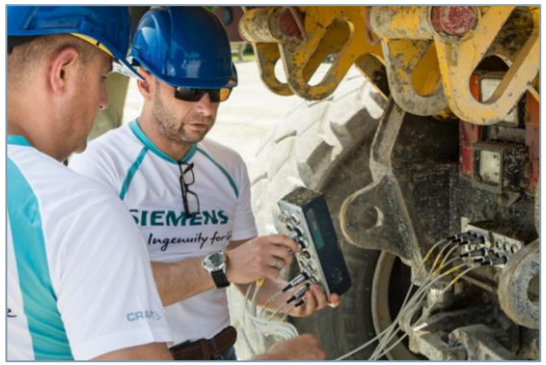
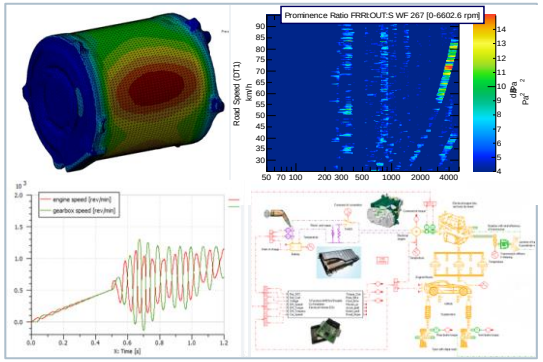
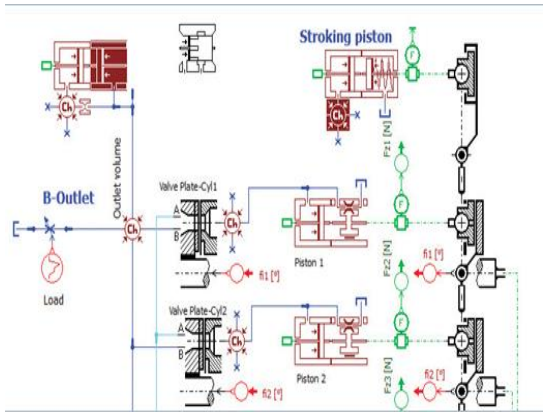


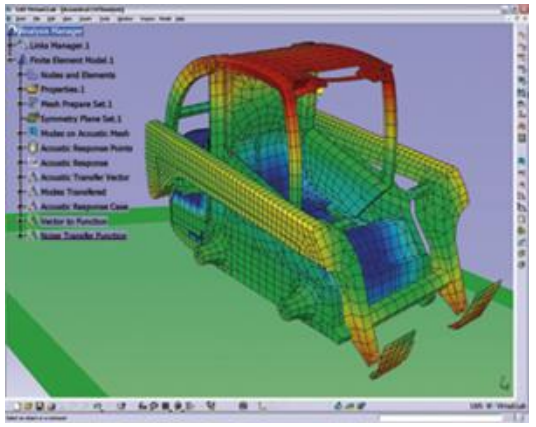
Highly skilled engineers



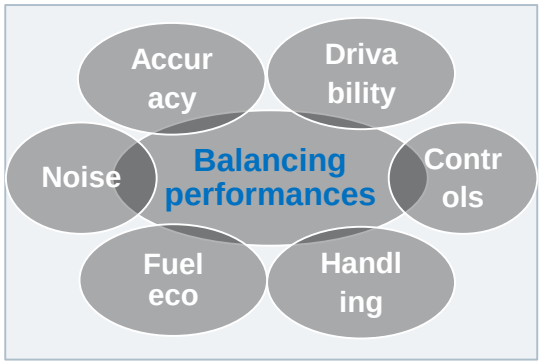
Process & technology



Expertise & know how



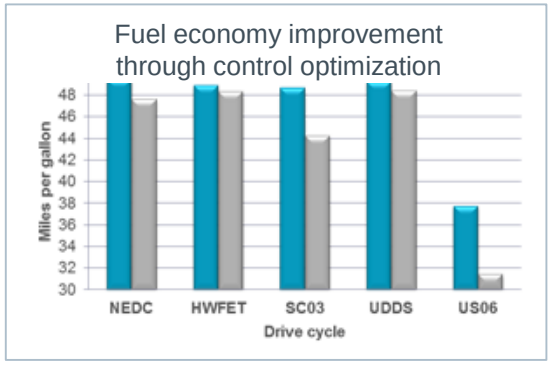
Infrastructure & tools



Multi-attribute engineering

Troubleshooting

Technology transfer



Co-development

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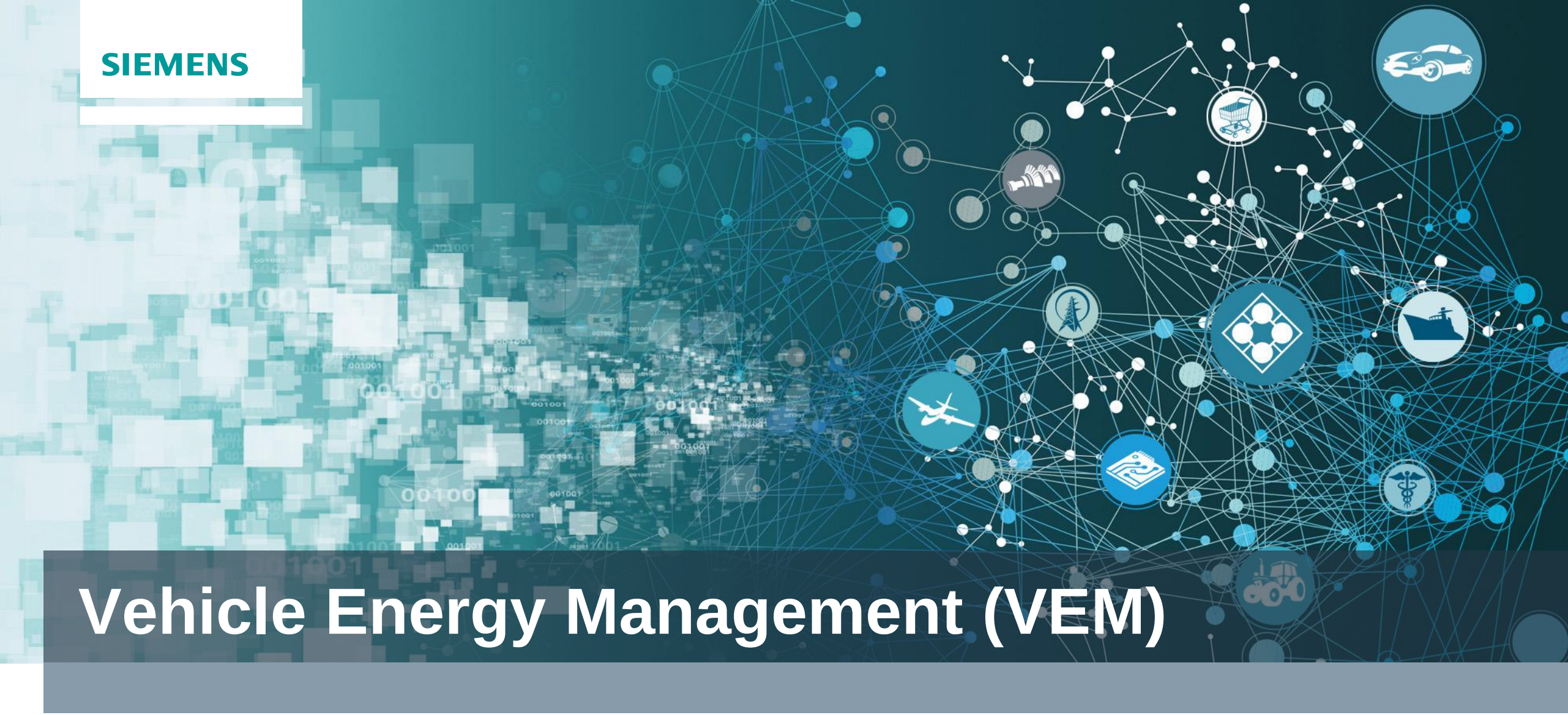

Vehicle Energy Management (VEM)

Vehicle Energy Management and Multi Attribute balancing

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In Today's world **fuel (energy) economy is driving the development** of vehicles.

Energy management has to **be balanced with other attributes early in the development process** to

- Meet regulations – Noise and Vibration
- Maintain or improve brand reputation vs competition

For off-highway and tucks VEM has to be, for example, balanced with:

- NVH
- Durability

→ **Adopt a system-driven development approach combining simulation & test to optimize performance throughout the development process**

Siemens integrated solution for VEM
A unique combination of services

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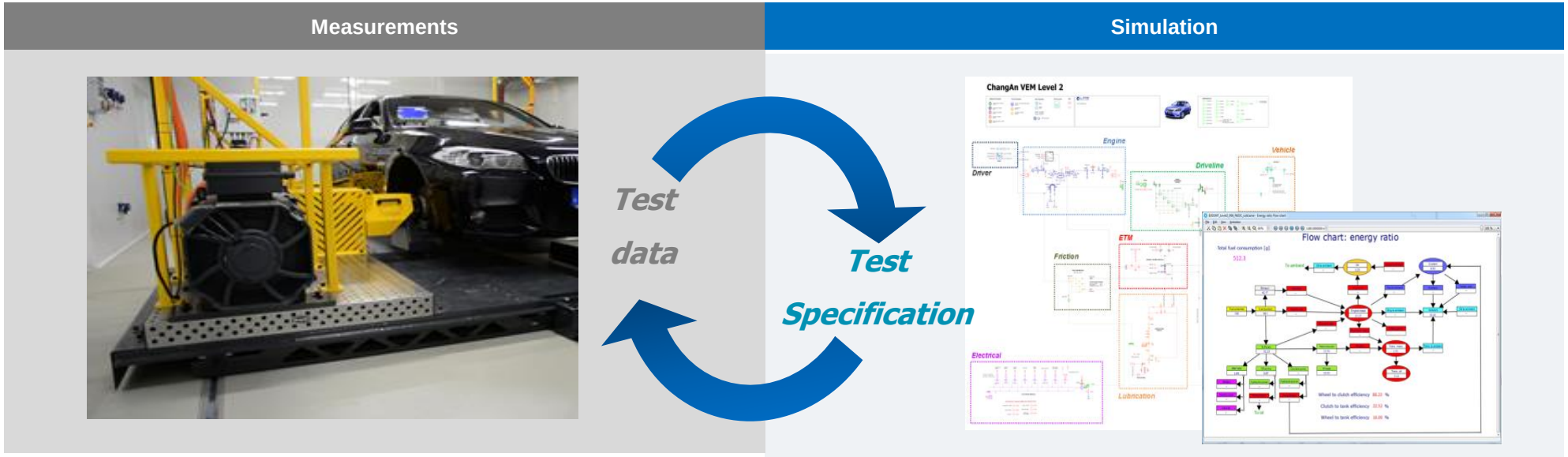
Siemens integrated offer for VEM

A unique, scalable offer of integrated test and simulation designed tailored for customer objectives

Flexibility and collaborative work

- Close interaction between simulation and tests teams with a continuous adjustment of measurements methods
- Test conditions easily shared, ensuring that each test can be properly used for modeling



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Our testing capabilities to support simulation



Key assets

- Brand new **climatic test cell**
- Innovative **wheel hub regulated drive**, tire uncertainty avoided
- A **driving robot** handles car driving operations
- All together supporting **testing combined simulation** projects

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Main Specifications

In a nutshell

- Max Mechanical Power: **125 kW** x **4** wheels
- Max Thermal Power: **300 kW** @25° C
- Max Torque per Wheel: **2000 Nm**
- Max wheel speed: **1400 rpm** (~160km/h)
- 2WD and **4WD**
- Temperature regulation: **-7° C to 45° C**
- Wind blower control: up to **140 km/h** (1x0,5m)
- Max Wheel-base: **4000 mm**
- Max Track: 2200 mm
- Max vehicle weight: **2800 kg**
- Usable height: 3,4 m
- Up to **250 signals** can be acquired simultaneously

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VEM applied to a tractor

Customer requirement

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- Need to **predict fuel consumption** before the first prototype is being built
- Need a scalable vehicle model to answer questions about architecture selection, system performance, component and **controls design**
- Match CO_2 reduction targets + Cut prototypes costs by frontloading vehicle validation

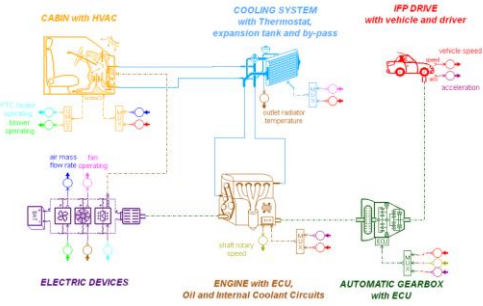
Vehicle Energy Management Methodology for a tractor

A scalable approach

VEM Phase 1

- **High level**, **functional** model of the tractor in AMESim
- Very fast CPU time, map/efficiency based model without thermal effects

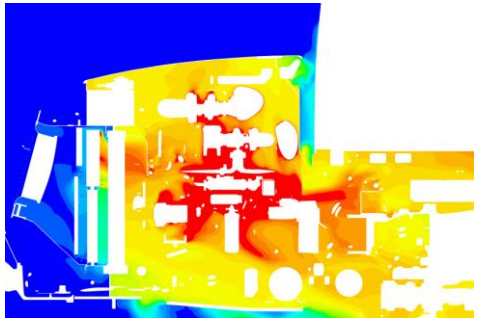
☞ Suitable for hot start fuel eco analysis and high level sensitivity analysis



VEM Phase 2 "Thermal"

- **All subsystems detailed** in AMESim according to their technology / physics and plugged together in the same model to add **Thermal behavior**
- **More physics inside, more predictability**

☞ Fuel economy, Energy and heat transfer, Flow charts



VEM outputs

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Fuel efficiency for various operating conditions

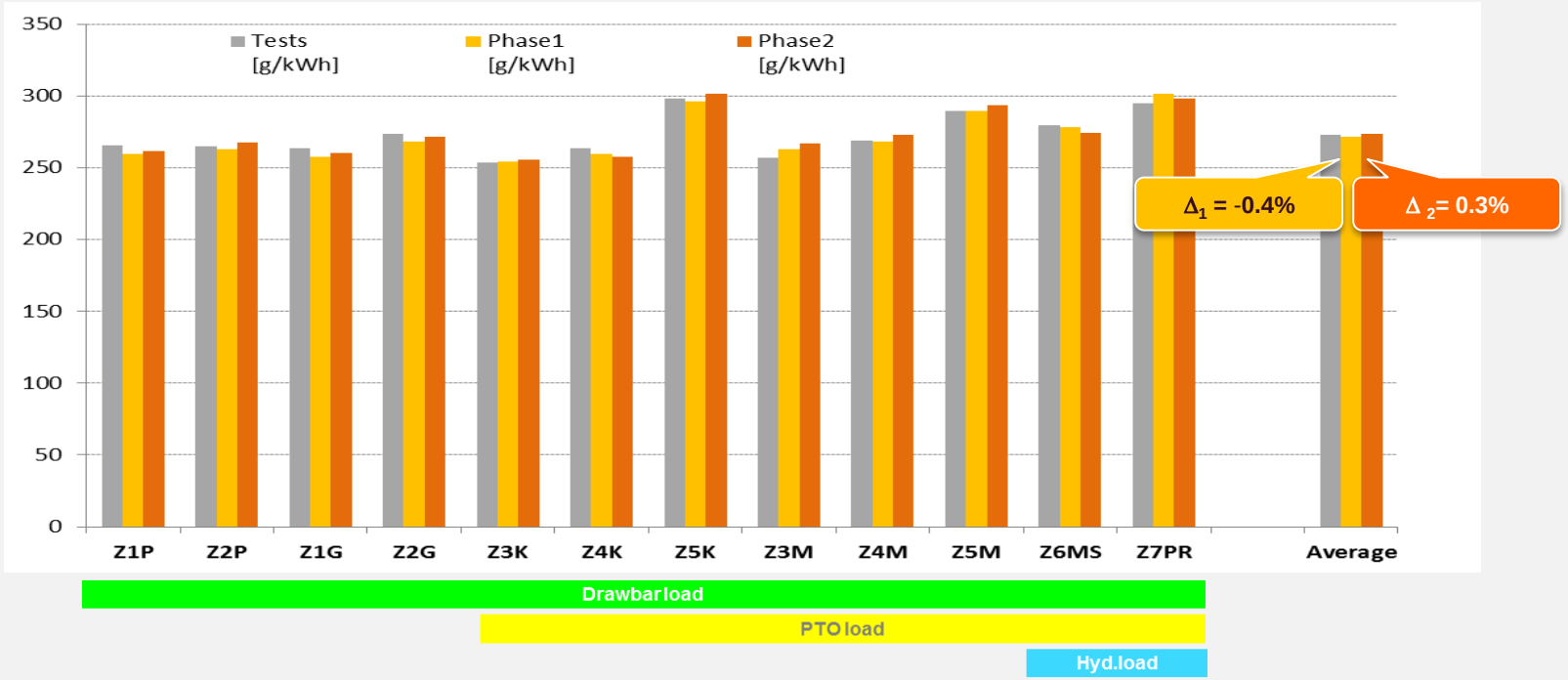
"PowerMix" fuel efficiency results: **very high fidelity from Phase 1 and Phase 2 models**

- Average deviation < 0.5%
- Max deviation for each cycle < 2.5%

PowerMix setup

Cycle	no load kph	eRPM	PTO rpm	Classification
Z1P	9	1800		heavy drawbar work
Z2P	9	1400		medium heavy drawbar work
Z1G	12	1800		heavy drawbar work
Z2G	12	1500		medium heavy drawbar work
Z3K	6	1780	900	heavy pto work
Z4K	6	1580	900	medium heavy pto work
Z5K	6	1580	900	light pto work
Z3M	16	1780	900	heavy pto work
Z4M	16	1580	900	medium heavy pto work
Z5M	16	1580	900	light pto work
Z6MS	7	1760	1000	drawbar, pto and hydraulic power
Z7PR	10	1760	1000	drawbar, pto and hydraulic power

$$BSFC = \frac{1}{t_{end}} \int_0^{t_{end}} \frac{fuel\ rate\ [g]}{load\ [kW]} dt$$

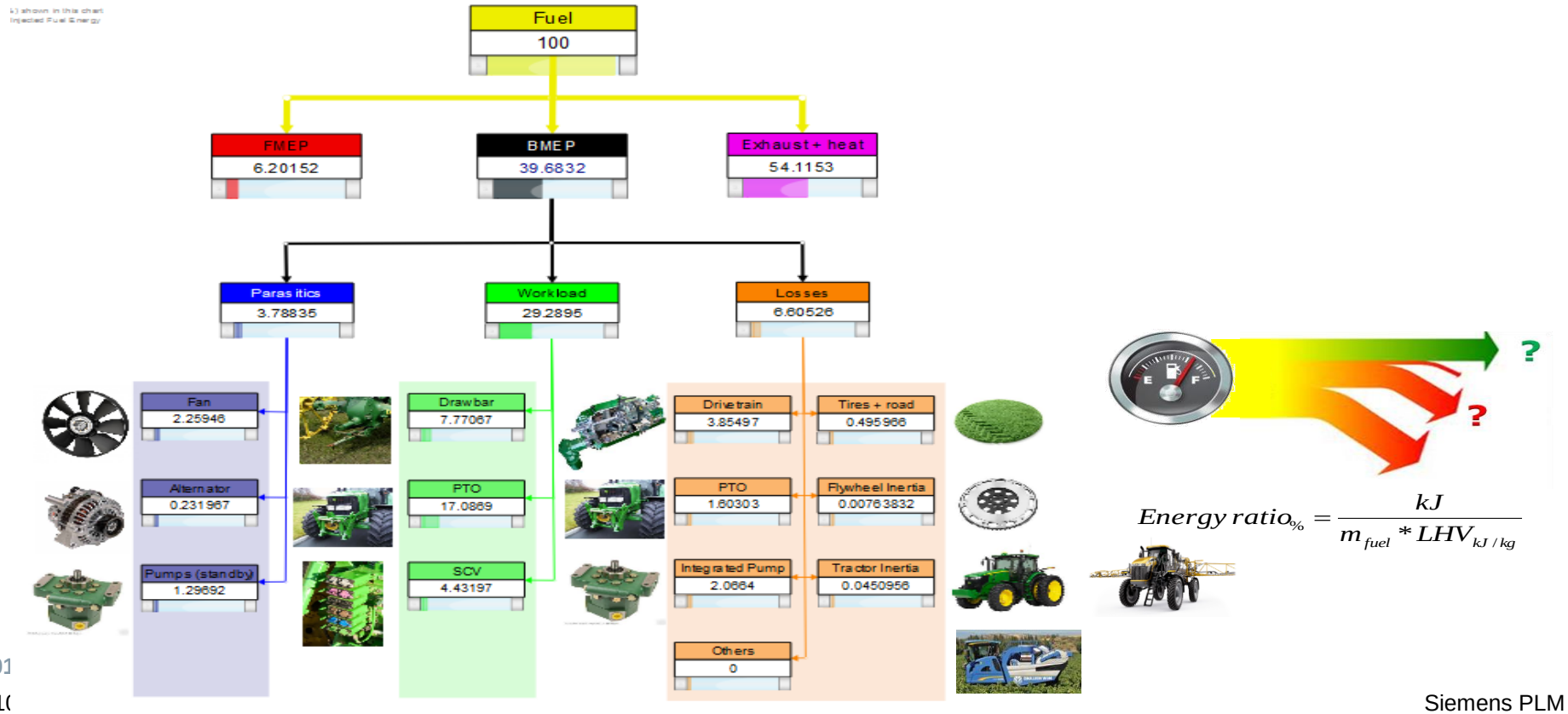


VEM outputs

Energy analysis with Flow chart

Energy flow charts enable **quick analysis of energy transfers inside the system**, tracking for best and worst efficient subsystems and eventually designing more efficient system

Energy Flow Chart for Phase 1 model

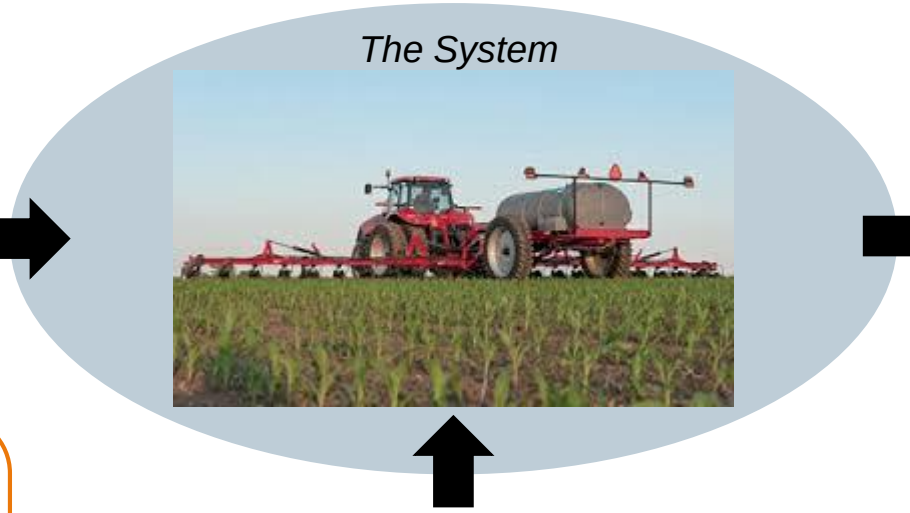


Next step: Optimal Control Problem

Problem description

The tractor pulling a slurry tank is a complex system whose dynamic performance is a function of multiple control inputs, uncertainties (noise factors).

Control factors:
1. Engine RPM
2. Transmission ratio
3. Hydraulic pressure
4. …



System Performance:
1. Minimize fuel consumption
2. Minimize time
3. …

Noise factors:
1. Changing mass
2. Road conditions – asphalt, mud, dry soil
3. Surface grade
4. Start/Stop
5. …

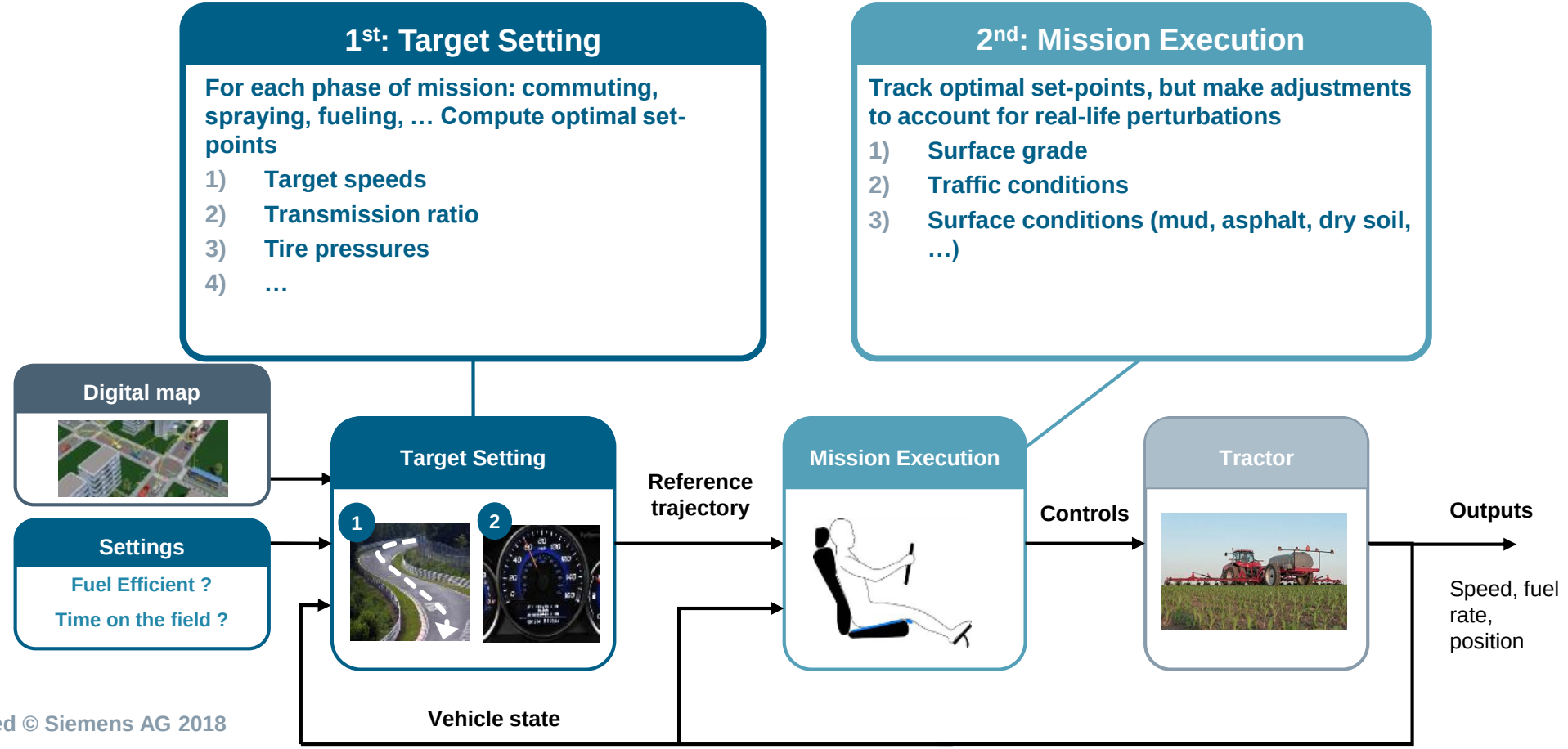
*There are **many combinations of valid control** inputs to operate over a mission.*

***Problem is to pick the control inputs which maximize the system performance**.*

Next step: Optimal Control Problem

Siemens Engineering Solution

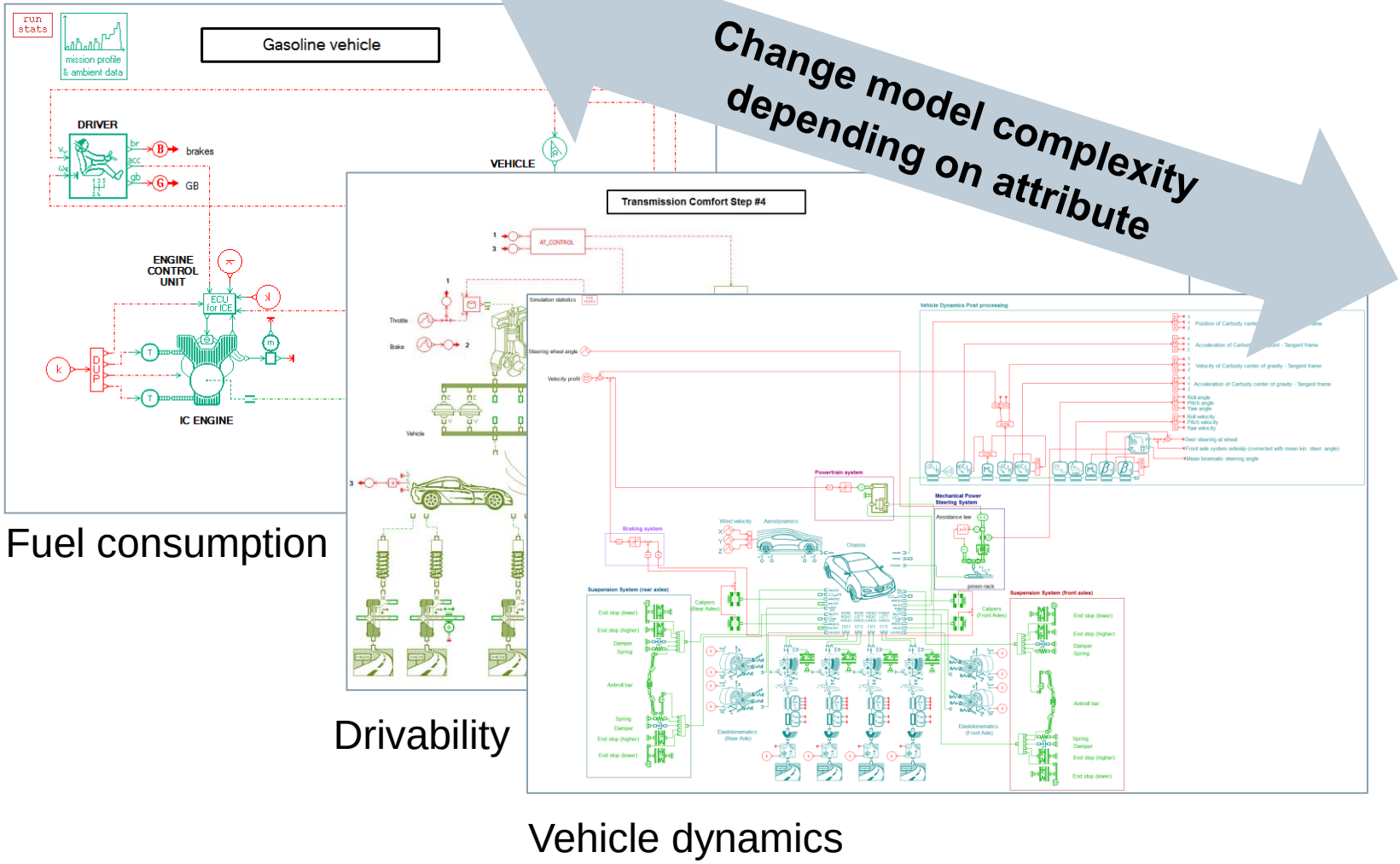
- An off-line analysis to map out the ideal control commands for each of the tractors operating modes: **“Target Setting”**
- A real-time embedded model control which works to achieve the optimal plan: **“Mission Execution”**



Model scalability

Analyze and organize the models developed for the different attributes

- Rewiring
- Identify common components



Example of Multi-Attribute Balancing Tool

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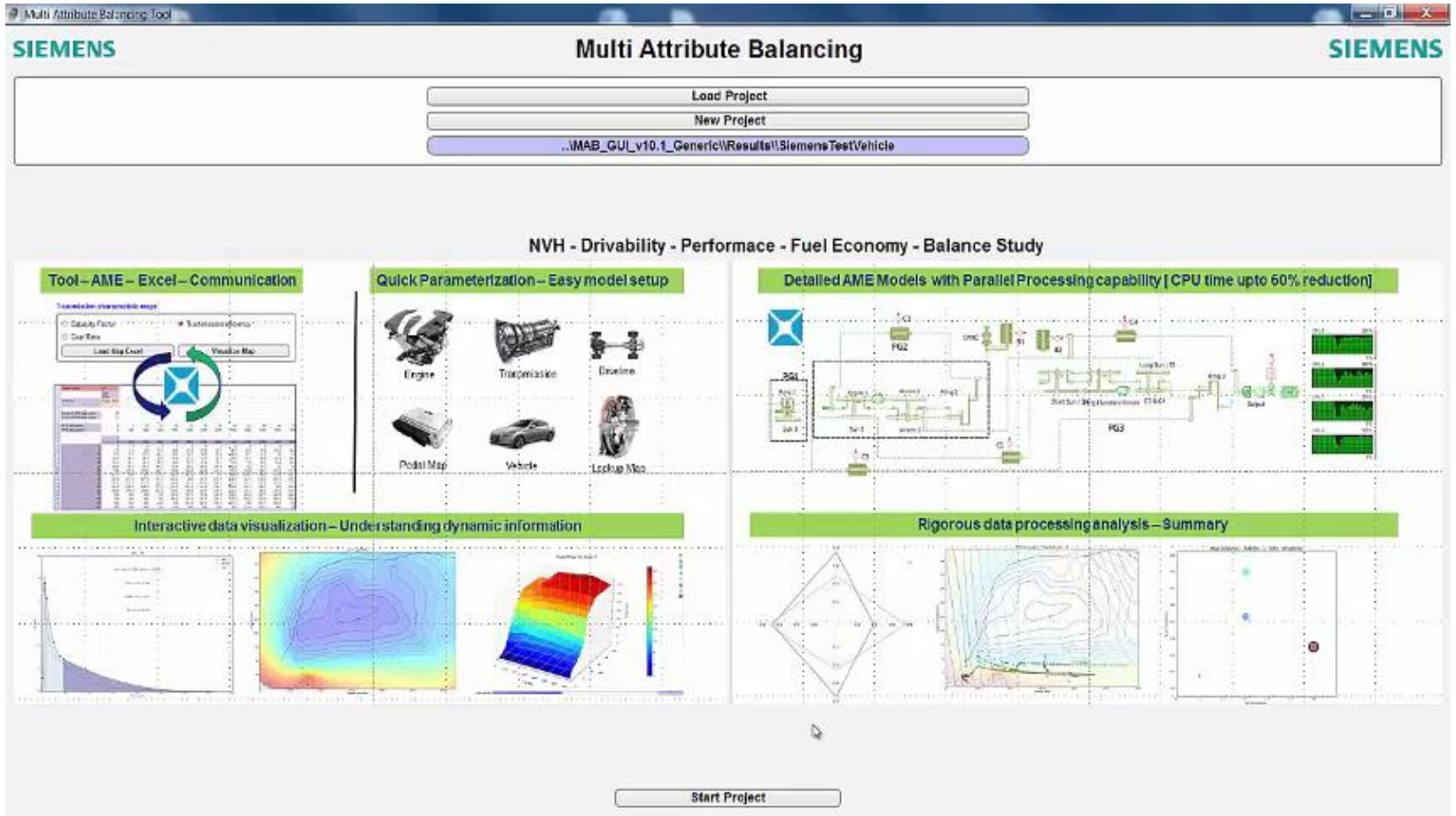

Attribute	Measure	weighting	Parameters
fuel eco	gram fuel	A	pedal-map, C-factor, gear-ratio, shift-pattern, rear-diff-gear-ratio, transfer-efficiency)
NVH	noise	B	
perfo	acceleration time	C	
drive-ability	rpm of TM/out (p2p)	D	
	rpm of TM/out (phase)		
booming	rpm of TM/out (order)	E	

Applications
(graphical design)

Platform
Heterogeneous modeling & simulation

Extensions
(modeling, compilation, simulation, analysis

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Multiple Attributes - ES experience

John Deere
Enabling resolving excessive cab noise - NVH

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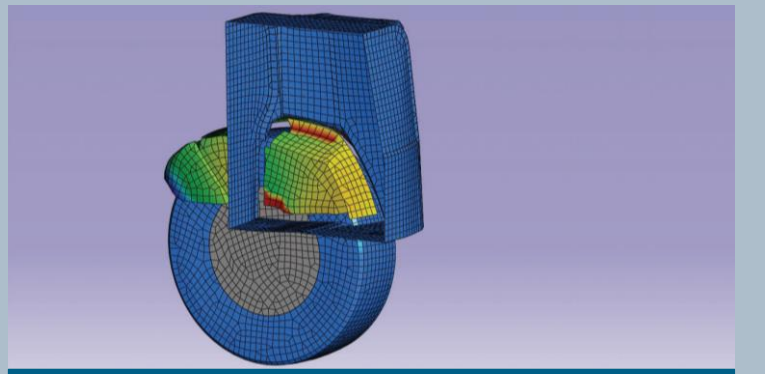
- **Developed approach for addressing acoustic issues early in the development process**
- **Quickly and efficiently identified effects that lead to loud cab noise**
- **Enabled better understanding of the complex acoustic system**

Experimental and numerical acoustic analysis

NVH testing



Acoustics simulation

- Use a combination of experimental and numerical acoustic analysis techniques
- Use LMS Engineering services and LMS software to identify and resolve issues

“We were able to identify the sensitivities of the different effects contributing to the cab noise phenomenon much faster and more efficiently through our cooperation with LMS Engineering services.”

Dr. Ing. Christian von Holst, Group Leader, Suspension Systems

Volvo Construction Equipment

Enhancing acoustic comfort with the help of LMS Testing Solutions - NVH

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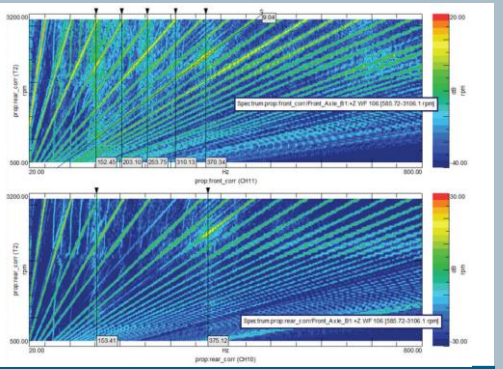
- **Made significant progress toward solving whining noise in the cab**
- **Discovered the need to improve the quality of the gears to reduce vibration**
- **Gained deeper insight by performing torsional vibration analysis**

Addressing NVH issues

address NVH issues

Close to the front axle flange

Close to the center bearing



Torsional vibration of the front prop shaft

- Add a mass of about 10 kilos to change dynamics of the shaft and improve behavior
- Save time with easy-to-use LMS Test.Lab software

“The solution to this whining noise problem is just one example of how LMS Testing Solutions from Siemens PLM Software helps VCE achieve its commitment to quality.”

Reza Renderstedt, Team Leader, Testing NVH for loaders

AGCO

Shroud design exploration ensures optimal cooling fan performance - VTM

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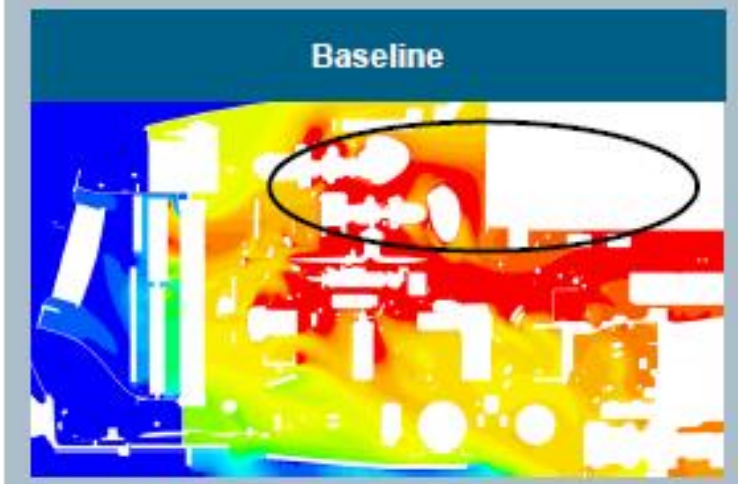
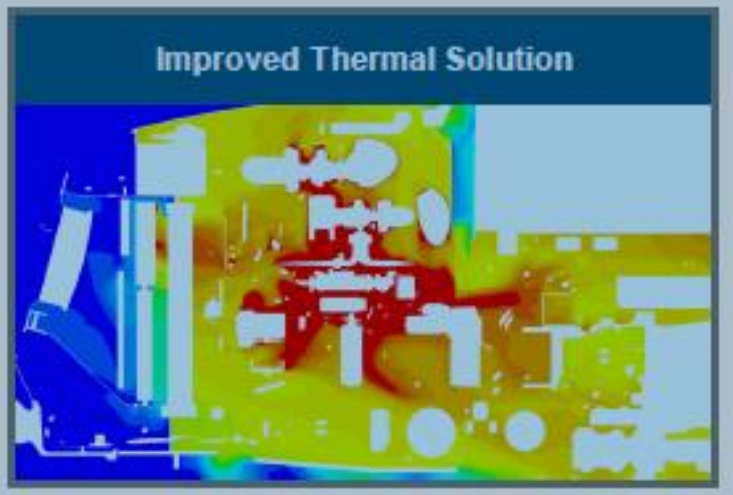
- Reduced design turn-around time
- Reduced peak temperature in engine compartment
- Ensured proper cooling air

Driving innovation through design exploration





"STAR-CCM+ offered complete CAD-to-mesh process with reduced turn-around time over existing in-house tools. This enabled us to bring in-house the simulation that was previous done by outside consultant allowing us to reduce cost, as well as improve our design." AGCO

AGCO

Using LMS software and services to develop high-performance crop sprayer

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- **Optimized the sprayer design for stability and productivity**
- **Outperformed industry standards for the coefficient of variation of the spray distribution pattern**
- **Added significant value to the Challenger brand**

Surpass industry standards and enhance the Challenger brand

Designing stable boom arms

A smooth ride on rough terrain

- Model the spraying system using **multi-body simulation**
- Use vibration testing and analysis for physical prototype validation

“Having a list of materials beginning with the engineering of the product will allow us to compare and check that all of the information and materials necessary are present, without missing a single component.”

Roberto Castrillo, Product Engineering Manager

CUCO for OFFROAD
Focus on fatigue damage

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Baseline data for correlation model / ML training (80+ channels)

Traditional measurement with full instrumentation + CuCo lean setup

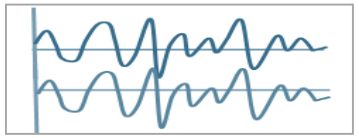
Fleet campaign @ Customer training (20-30 channels)

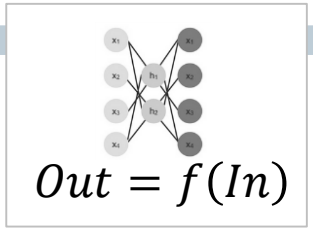
CuCo lean setup
data logger + observer channels

Model: Inputs → Outputs

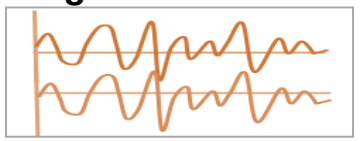
- Data correlation & analysis
- Machine Learning approach

Observer channels



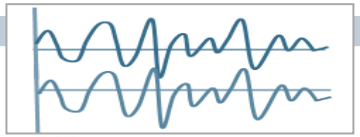


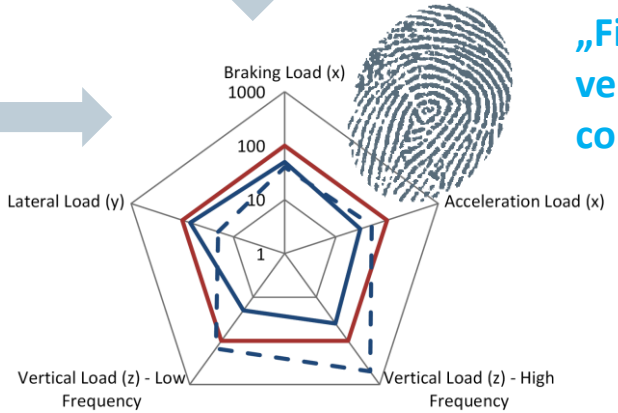
Target channels



Correlation model/function

Observer channels





„Fingerprint“ of major vehicle loading components

Kverneland Group

Enabling farming equipment firm to enhance durability of its products - Durability

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- **Enhanced measurement capabilities under a variety of conditions**
- **Reduced time and cost by automating measuring process**
- **Improved ability to acquire the most diverse data from sensors**

Collecting more proof points

Providing results that reflect the majority of load conditions

Verified test track or procedure that matches the customer's usage

- Deliver more detailed load profiles
- Enhance knowledge of load history

"Our engineers are very happy with the insight delivered by this information. Over time, this improved insight will help define standard profiles to reproduce realistic tests in the lab."

Jan Vestergaard Madsen, Head of the Design Department

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