A case study in credibility assessment of system models for energy efficiency analysis of passenger cars

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Outline

1. RISE overview
2. Does quality of numerical simulations matter?
3. Quality Assurance (QA) of numerical simulations: ***Simulation Governance*** and ***Simulation Management***
4. RISE journey so far:
    1. Project SPRUCE
    2. Project STEERING:
        1. Case study: VSIM
    3. Project TRUSTIT


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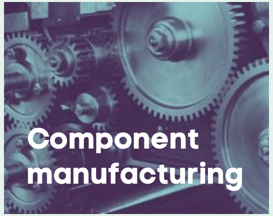
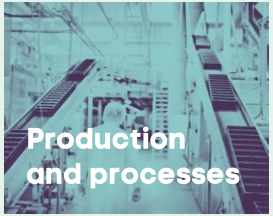
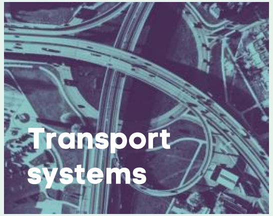
We are Sweden´s
research institute

Group-wide research areas







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RISE Chemistry & Applied Mechanics

- ~ 70 (100) co-workers in Borås, Gothenburg, and from former SMP in Uppsala and Umeå
- Node for solid and structural mechanics at RISE
- Large experimental resources for mechanical testing and modelling (material/component/structure). Research + industrial assignments.
- Active in most industrial sectors (construction, energy, infrastructure, automotive)
- Core business: ***product verification*** (often for the purpose of ***certification***). Accreditation for several methods.

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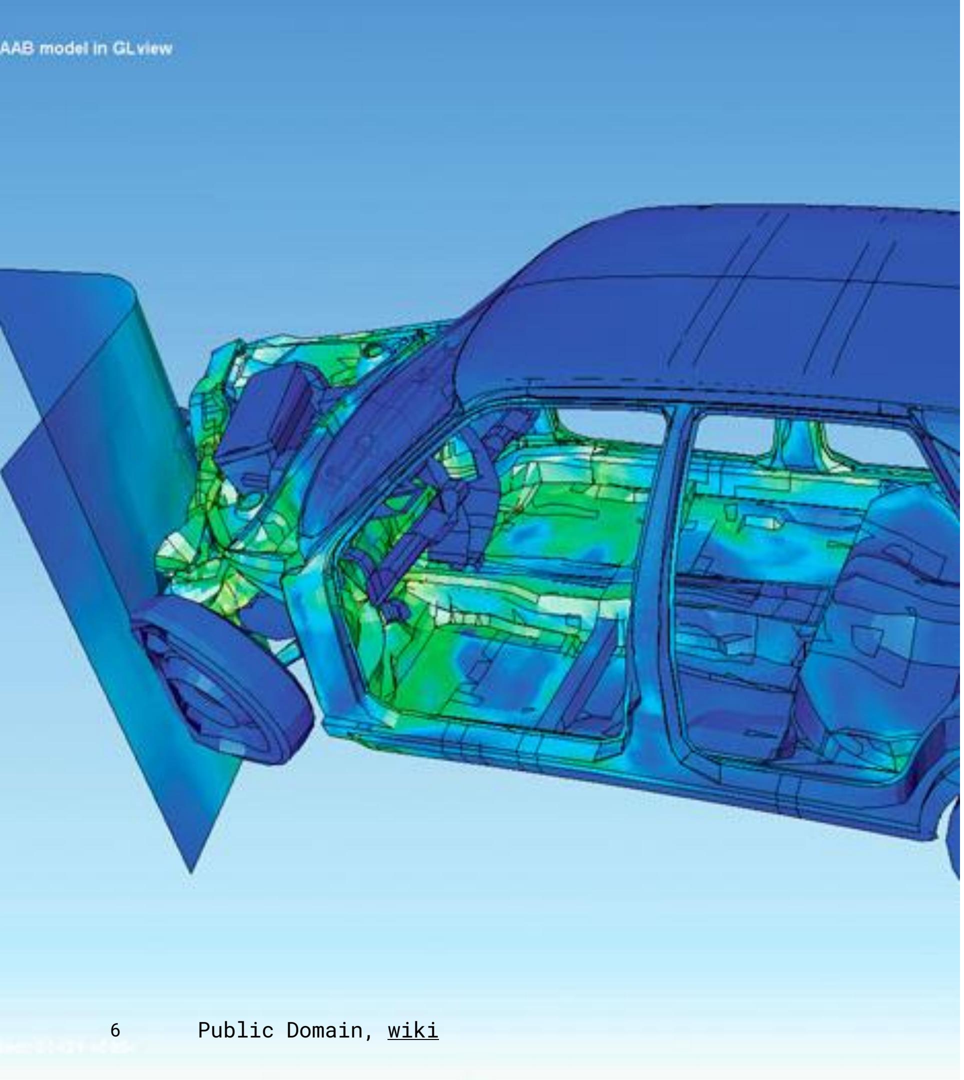


From physical testing to virtual testing

- Growing role of numerical simulations in product developement and ***decision - making processes*** (e.g. design, engineering, monitoring, maintenance)
- ***Reliability*** and ***safety*** of products are traditionally based on ***physical testing***, quality control and certification processes. Conformity assessment via numerical simulations is gaining acceptance
- Can we ***trust models*** as much as measurement devices?
- Are current standards adequate to safely perform ***conformity assessment*** via numerical simulations?
- Are ***quality standards*** for numerical simulations widely adopted in industry?

Public Domain, wiki

Example 1: fire safety of structural elements

Why bother? What can go wrong?

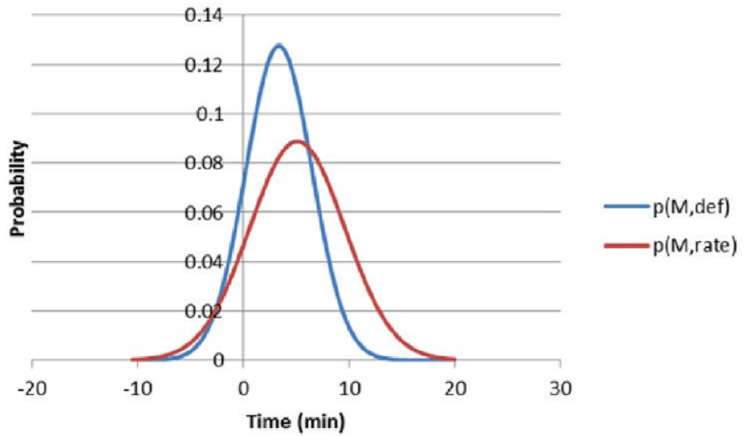
Fire Safety Journal 92 (2017) 64–76

A round robin study on modelling the fire resistance of a loaded steel beam

David Lange *, Lars Boström

RISE Research Institutes of Sweden, Safety and Transport/Fire Research, Sweden

[...] calculations or simulations are now often used as an alternative means of evaluation of structures exposed to fire compared with testing. For building elements and structures in Europe the Eurocodes are the basis for design, and these allow calculations in simple or advanced design methods. For certification of certain building products calculations have the same credibility as testing. However, while for testing there are requirements on accreditation of the test laboratory as well as follow up inspections, this is not the case for calculations. In other words, when evaluating building products for certification based on testing there is a formal control system that must be followed. This type of control does not exist when doing the same job based on calculations.



$M \sim T - C$ (Prediction by Test – Prediction by Calculations)

$Prob(M < 0 \equiv$ unsafe calculation$)$ ≈13%

Example 2: CAC – Computer Aided Catastrophes

The sinking of the Sleipner A offshore platform

Excerpted from a report of SINTEF, Civil and Environmental Engineering:

The Sleipner A platform produces oil and gas in the North Sea and is supported on the seabed at a water depth of 82 m. It is a Condeep type platform with a concrete gravity base structure consisting of 24 cells and with a total base area of 16 000 m^2. Four cells are elongated to shafts supporting the platform deck. The first concrete base structure for Sleipner A sprang a leak and sank under a controlled ballasting operation during preparation for deck mating in Gandsfjorden outside Stavanger, Norway on 23 August 1991.

Immediately after the accident, the owner of the platform, Statoil, a Norwegian oil company appointed an investigation group, and SINTEF was contracted to be the technical advisor for this group.

The post accident investigation traced the error to inaccurate finite element approximation of the linear elastic model of the tricell (using the popular finite element program NASTRAN). The shear stresses were underestimated by 47%, leading to insufficient design. In particular, certain concrete walls were not thick enough. More careful finite element analysis, made after the accident, predicted that failure would occur with this design at a depth of 62m, which matches well with the actual occurrence at 65m.

Douglas Arnold, University of Minnesota for more CAC

Timeline

SmartSE

UpSIM

VaVim

EVIDENT*

EVIDENT
(RISE, VCC,
HUSQARNA,
SCANIA)

- 2014: **Virtual Nation Agenda** (SWEREA)
  Mapping of numerical simulations in Swedish industry
- 2019 – 2020: **SPRUCE** (RISE, VCC, Validus, FS Dynamics)
  Standardization Practices for a Responsible Use of Computational models in Engineering: *How you build confidence in numerical simulations?*
- 2020 – 2022: **STEERING** (RISE, VCC, Validus)
  Standardization experiments for enhanced reliability of engineering simulations: *Do standards help to manage the quality of numerical simulations?*
- 2023: **TRUSTIT** (RISE, VCC)
  Towards a rational approach to credibility of numerical simulations in industrial applications: *How to implement credibility assessment in product development?*

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Project SPRUCE (2019-2020)

Standardization Practices for a Responsible Use of Computational models in Engineering

Goals

- To map current practice and needs for standardization, quality assurance of numerical simulations in industry
- Roadmap/ strategy for standardization in quality assurance of numerical simulations in industry

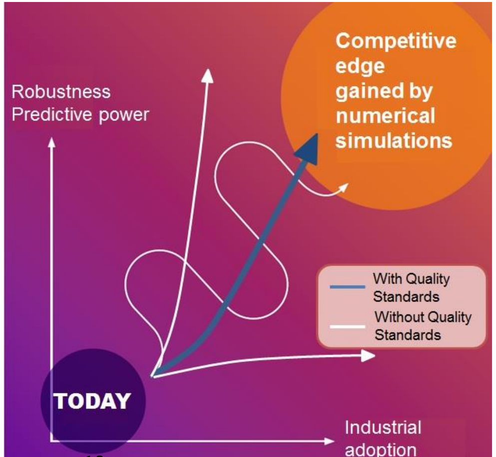
Data collected via survey and interviews with industrial practitioners.

Collaboration with Volvo Cars, Validus Engineering, FS Dynamics

Budget 1.075 Msek (~80% funding from VINNOVA)

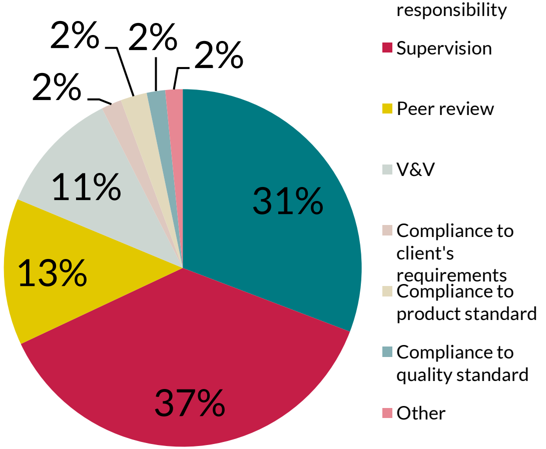
Product standards rarely provide guidance for credibility assessment of simulations.

Scarce integration between CAE activities and Quality Management System: why?

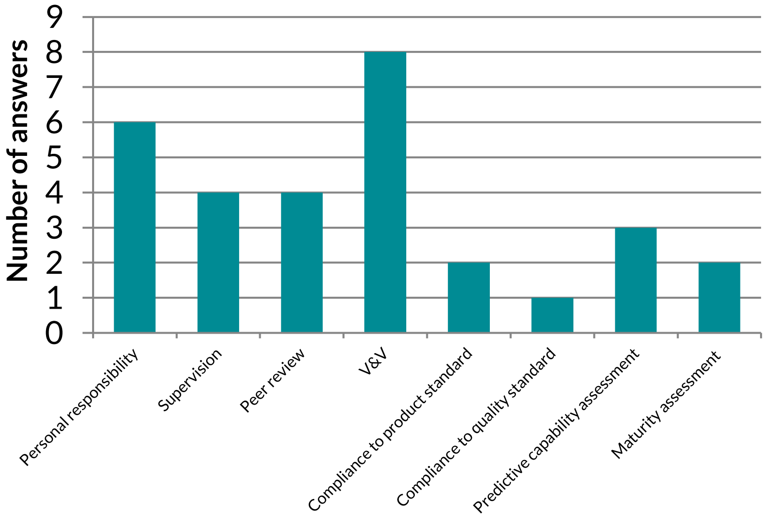


Quality/credibility assessment

Methods for quality assurance of numerical analysis



Potential for improvement



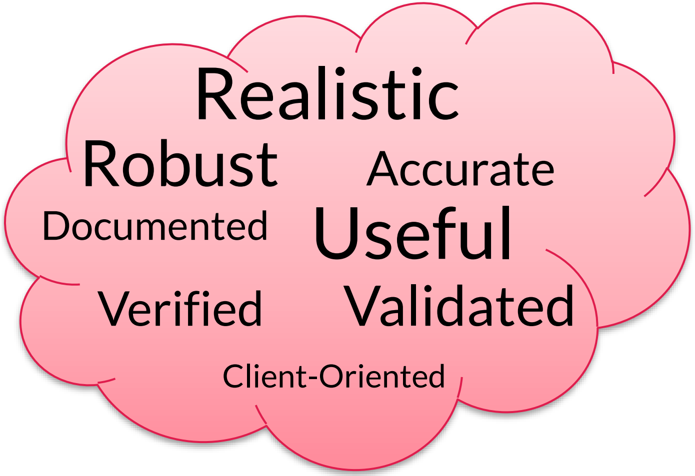
Project SPRUCE (2019-2020)

Standardization Practices for a Responsible Use of Computational models in Engineering

Industrial practitioners associate a variety of attributes to quality of numerical simulations:

Dominant approaches to Quality Assurance (QA) of numerical simulations

personal responsibility
informal review



Source:
SPRUCE project 2019-2020
RISE, Validus, Volvo Cars, FS Dynamics
Funding from VINNOVA

ISO 9001 definition (inherited in NAFEMS ESQMS 2020):

"**<u>quality</u>**: *degree to which a set of inherent characteristics of an object fulfils requirements.*"

Requirements are set by *clients*. In the case of simulations →

What requirements?
Who are the clients?

Simulation Governance

Quality Assurance (QA) of numerical simulations means a systematic way to mitigate the *risk for unwanted consequences* of model-based decisions.

QA of numerical simulations is a *multi-layer* process: (Oberkampf & Imbert, 2018)

Simulation Governance: assessment of the processes defined within the organization for the whole lifecycle of the models (e.g., *specification*, *development*, *deployment*, *documentation*, and *archival*).

↓ implementation

Simulation Management: credibility assessment of a specific model (*can we trust model results for the intended application*?)

QA can be integrated in early stage of product development

Methodology for Predictive Design Analysis (Eriksson, 2015)

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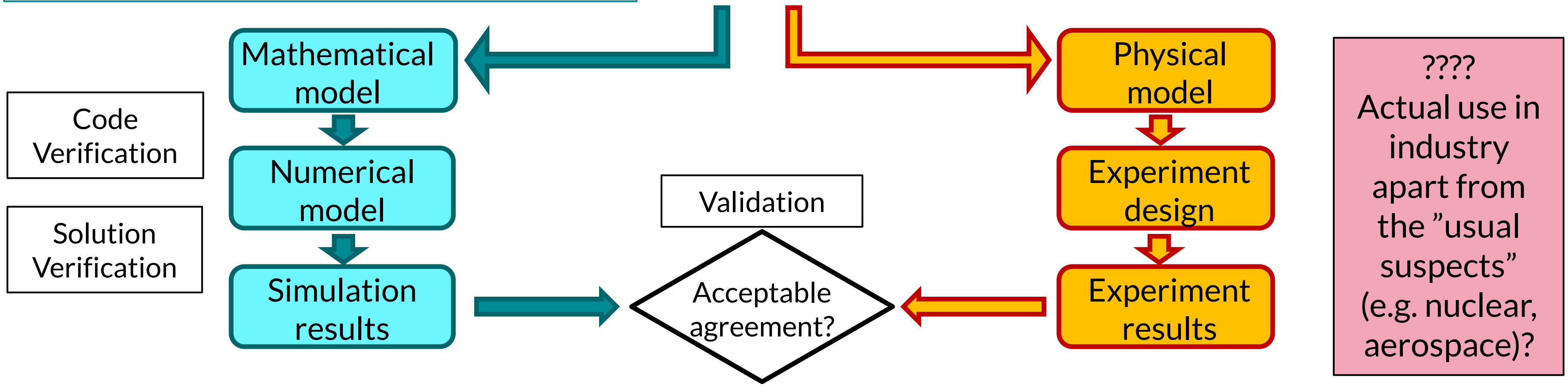
Verification, Validation, and Uncertainty Quantification (VVUQ)

Verification: The process of determining that a model implementation and its associated data accurately represents the developer's conceptual description and specifications (*model built **right***).

Validation: The process of determining the degree to which a model and its associated data are accurate representations of the real world from the perspective of the intended use(s) (***right** model built*).



Standards exist for V&V: (structural mechanics, fluid dynamics, etc) by international organizations such as ASME and IEEE.
More limited guidelines for UQ (e.g. GUM for exp).

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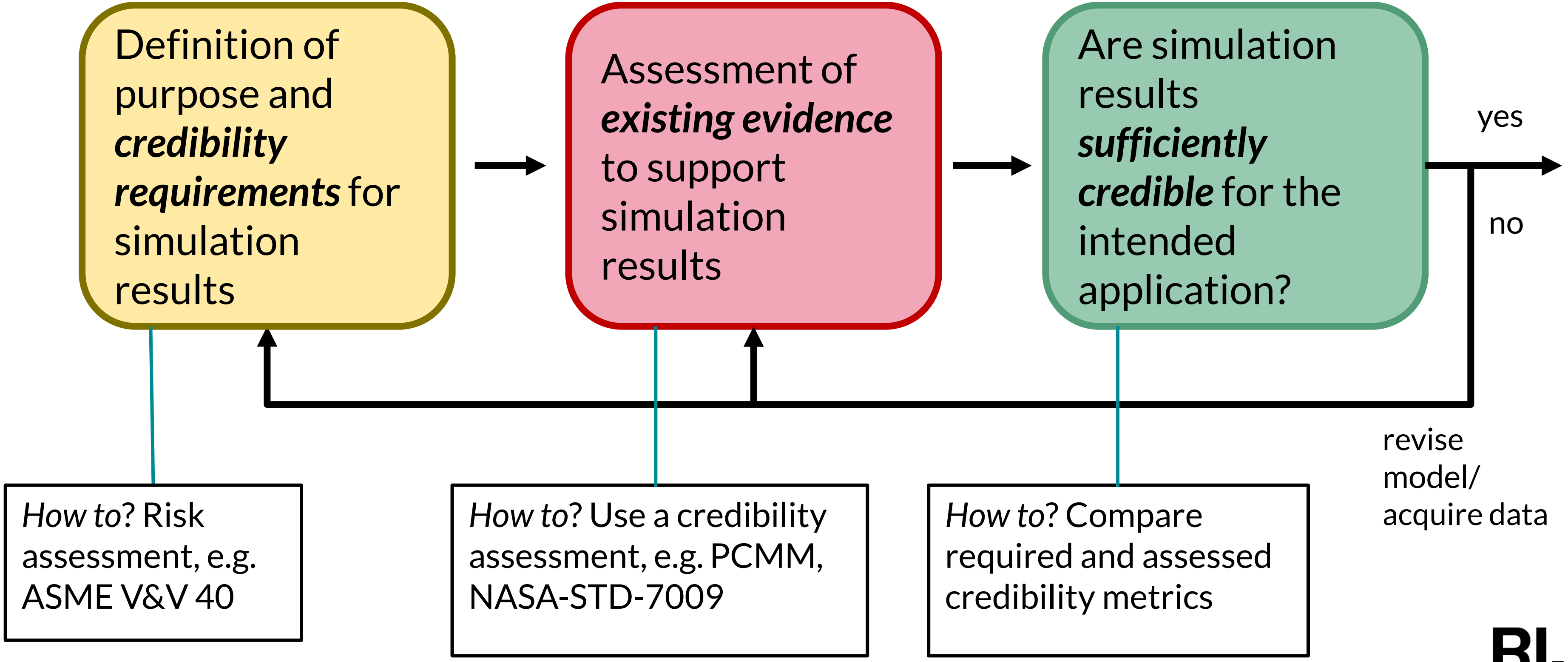
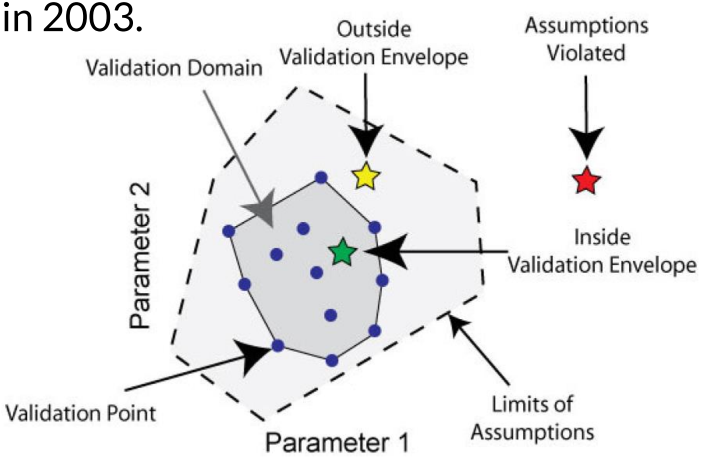
Credibility Assessment Process



NASA 7009 Standard for M&S Credibility Assessment Framework

- Dedicated standard for Modelling and Simulation (M&S).
- Outcome of internal revision after Columbia shuttle accident in 2003.
- Quality management and risk assessment of using M&S.
- Lifecycle view of M&S:
  1. **Header**
     General info on model and related Real World System
  2. **M&S Planning**
     criticality assessment, best practices, training, …
  3. **M&S Development**
     modelling technique, model scope, verification, …
  4. **M&S Use**
     credibility assessment, people qualification, technical reviews, risk for decision-making, …



Model credibility

Level	Data Pedigree	Verification	Validation	Input Pedigree	Uncertainty Characterization	Results Robustness	M&S History	M&S Process Management
0-4								

Scores 0-4 are assigned to each sub-item by evaluators.
The client/decision-maker is responsible to set target levels

Project STEERING (2020-2022)

Standardization Experiments for Enhanced Reliability of engineerING simulations

Case studies		
Technical area	**Model/Application**	**Standard**
Structural Mechanics	FEA for certification of scaffolding systems	PCMM, (Credibility)
Structural Mechanics	FEA for certification of crash safety barriers	FDA Guidelines (Credibility + review)
Fluid Dynamics	CFD for aerodynamics analysis	CGNS (Traceability)
System Modelling	Model-based estimation of vehicle energy management	NASA-STD-7009 (Credibility)

January 2021 – Jun 2022

Budget: 1 460 715 sek

Project partners

RI. SE Research Institutes of Sweden | Validus engineering | VOLVO

Funding from VINNOVA Sweden's Innovation Agency is gratefully acknowledged (Diarienummer: 2020-04409)

- Simulation to support certification
- Traceability of simulation data
- Interoperability

Does **standardization** facilitates **decision-making** based on numerical simulations?

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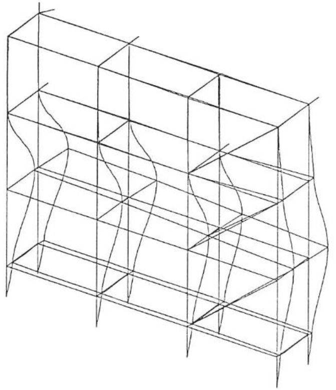
Case study: structural mechanics 1
Certification of prefabricated scaffoldings

- Regulatory framework

EU Directives →AFS 2013:4 (***type control***) → Harmonized EU standard EN 12811 →RISE method

- Component testing: load-bearing members, coupling elements



- Full scale testing + FE model (8m, 3 bays): structure identification
- Product classification based on FEA results of conservative 24m, 5 bays model

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Case study: certification of road restraint systems

- Regulatory framework: EN 1317:2010. Product classification based on conformity assessment.

- New products: ***physical testing*** required (crash test w cars and trucks)

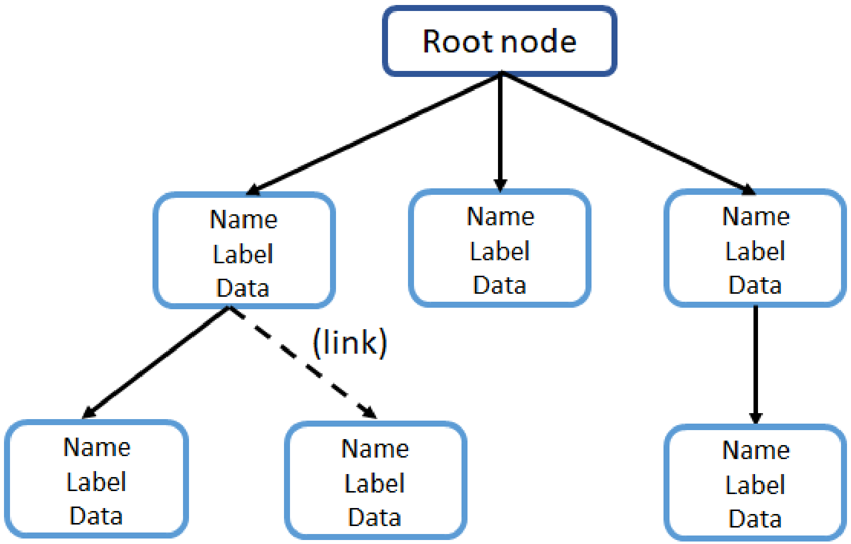
- Modified products: ***virtual testing*** allowed (for ”*small*” design changes)

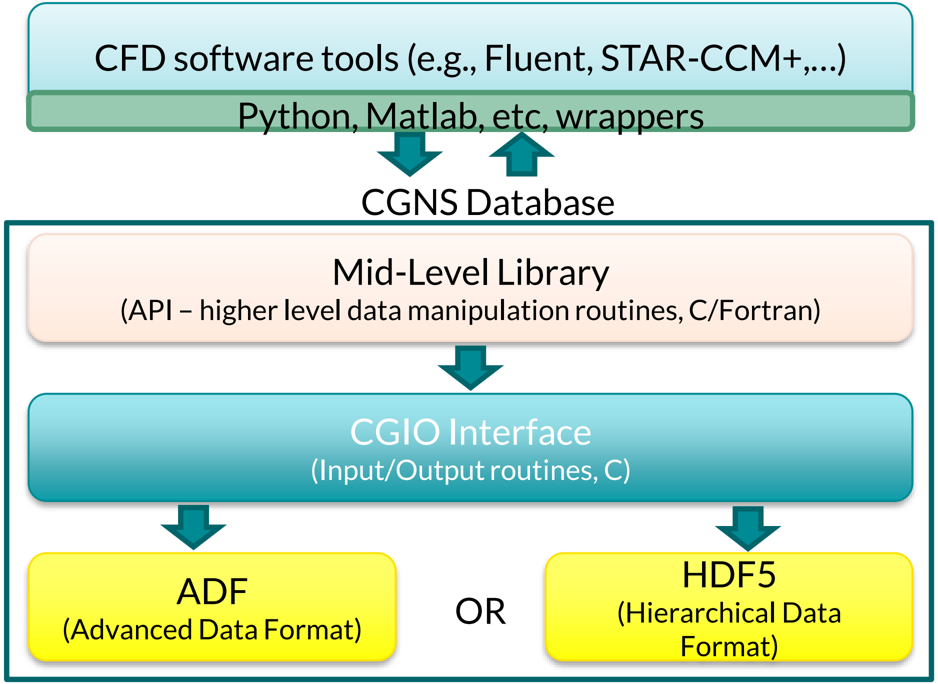
- Guide to V&V process of FEA and MBS: EN 16303:2020

- Third-party review with no access to the models, only ***analysis reports***

Case study: traceability of CFD data

What about CFD? **CFD General Notation System (CGNS)**



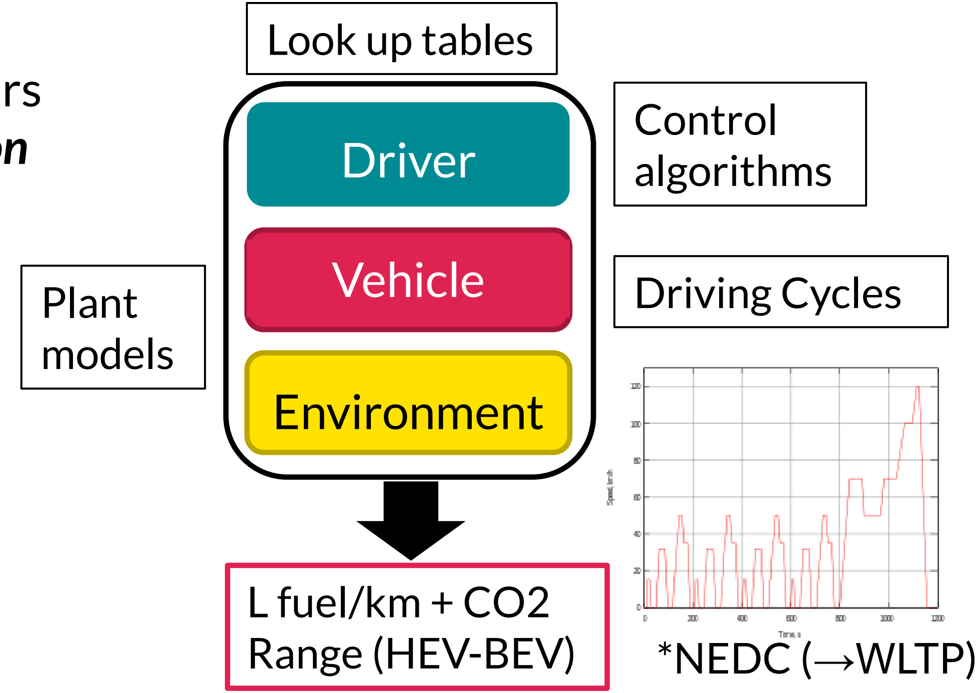


Case study goal: attempt to replicate results of analysis between 2 commercial solvers using CGNS as common output-input interface: <u>failed</u> (so far)! ☹

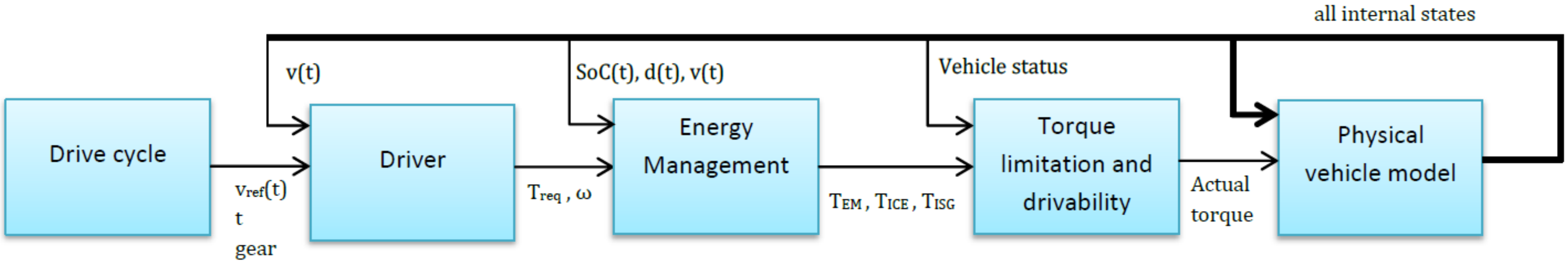
Case study: Systems Simulation

VSIM facts:

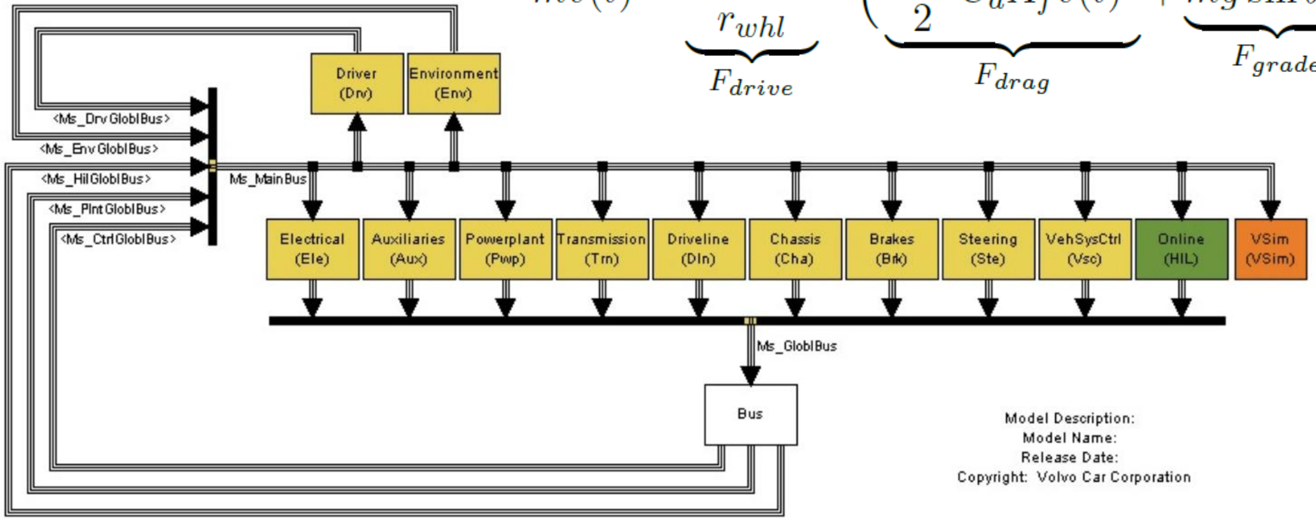
- Simulation tool developed at Volvo Cars for ***complete vehicle energy consumption*** (fuel economy) and dimensioning of powertrain components.
- Based on Matlab/Simulink.
- Different powertrains (ICE, hybrid, battery), different components
- Different groups responsible for components + 1 group for overarching structure, repository, version history



Case study: System Simulation



$$m\dot{v}(t) = \underbrace{\frac{T_{whl}(t)}{r_{whl}}}_{F_{drive}} - \left(\underbrace{\frac{\rho_{air}}{2} C_d A_f v(t)^2}_{F_{drag}} + \underbrace{mg\sin\theta(t)}_{F_{grade}} + \underbrace{f_r mg\cos\theta(t)}_{F_{roll}}\right)$$



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Case study: System Simulation

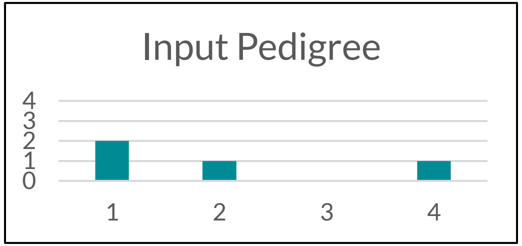
Credibility assessment based on NASA STD 7009

- Multidisciplinary evaluation team assembled (model development, tool maintenance, system/component design, ~~emissions testing~~)
- 2 workshops in person (~4 h each, 5+1 people) + e-mail
- Open questions in the worksheet: broad discussion, but focus!
- Substantial effort to explain the scope and purpose of the exercise.
- Risk analysis and requirements specifications: far from easy!
- Common view from individual assessments: utopia?

Case study: System Simulation

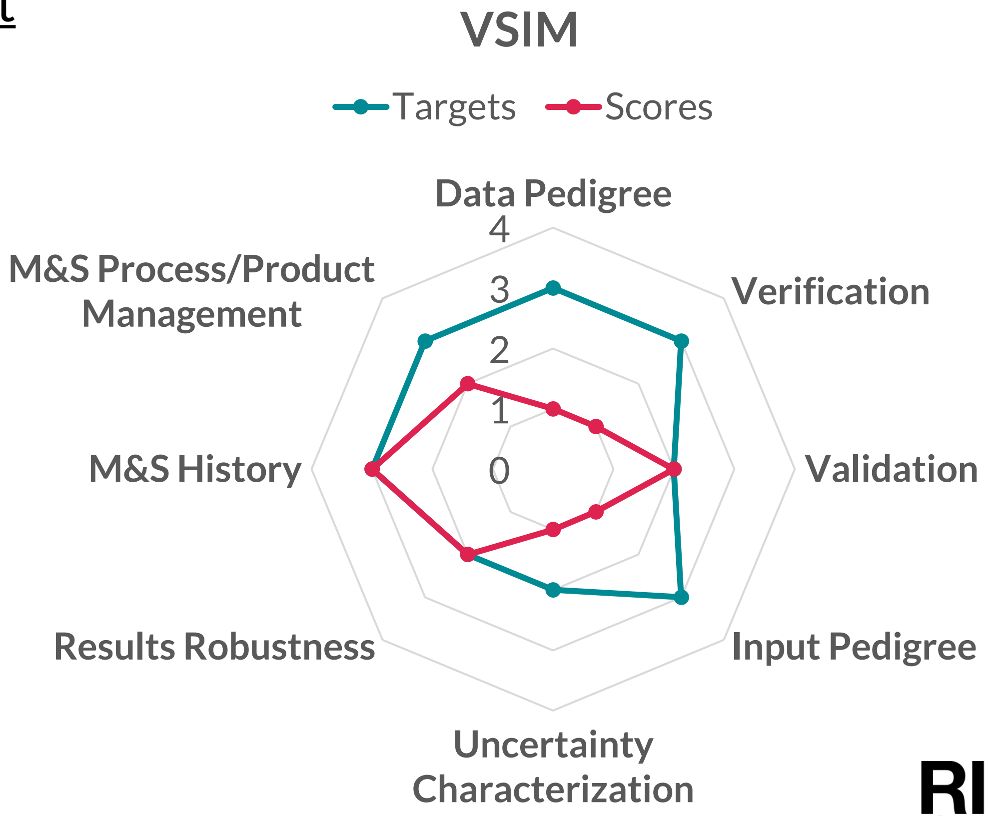
Outcome of CAS-based assessment

- Majority rule to determine single overall scores, ex.



- The ”devil” is in the comments, ex. M&S History no rating given:

”Very hard to assess since our tool is built up by many different models (components), some models are very stable, some are not.”



STEERING outcomes

- A structured approach to Quality Assurance of numerical simulations serves both for internal improvement and external third-party reviews.
- The process of reviewing numerical simulations is getting more standardized in some application areas (e.g., FDA templates + ASME V&V40), which is important to enable simulation-based certification (round robin on fire resistance example).
- UQ is by far the least practised part of credibility assessment.
- Growing interest in industry, e.g. Grundfos and others in VVUQ (NAFEMS), Simulation Supporting Certification (NAFEMS), the ACARE roadmap for simulation in certification of aircrafts, Simulation-Based Decision Making in SmartSE project.
- Credibility assessment frameworks and standards exist. Unclear level of implementation in industrial practice, apart from mature users in nuclear and aerospace: why? Lack of resources? Lack of awareness? Too scarce benefits?

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TRUSTIT Research/Strategic questions

1. How Simulation Governance can be practically integrated in current workflows for product development (e.g., based on SCRUM)? Activities with specific challenges: V&V, UQ

2. How to assess the impact of numerical simulations in decision making?

3. STEERING VSIM Case Study: further development -> more quantitative case studies, exchange between research and industrial practice

4. How to express *useful* credibility requirements?

5. Role of open standards to manage models and metadata for credibility (e.g.: FMI, SSP, MOSSEC)

6. Alignment with internal strategies for virtual verification at Volvo Cars

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