

# VirtMet in the wild: virtual metrology and virtual testing

Ms L. Wright, Dr. K. Khatri, Dr. M. Bevilacqua, Dr. L. Wright, Dr. M. Chrubasik,  
Dr. J. Gregorio

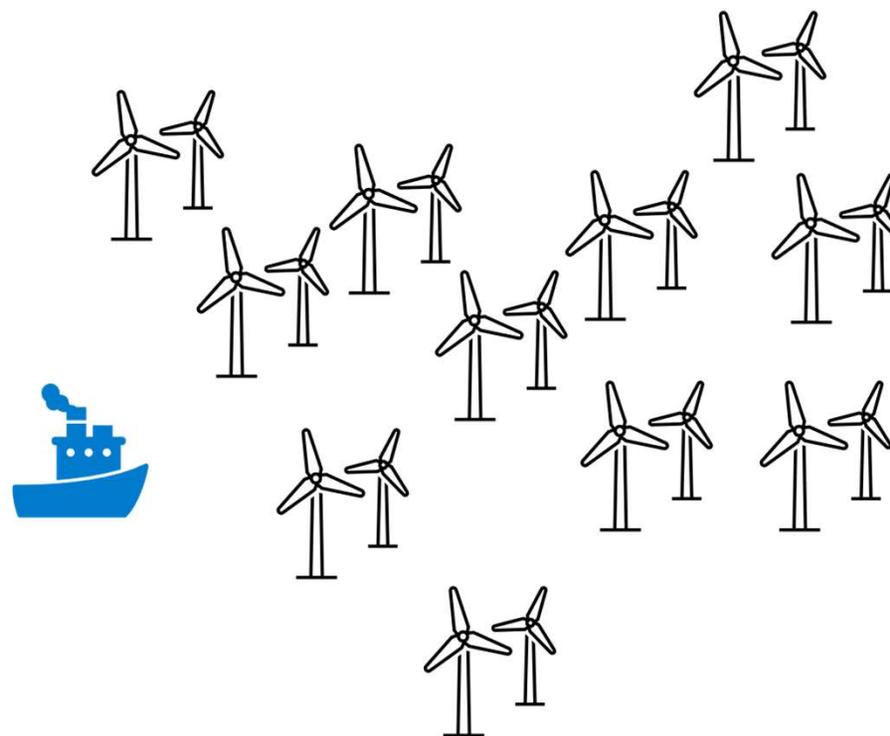
# Contents



- Three problems
- Twins, pyramids and environments
- Links and challenges
- Recent work towards meeting those challenges

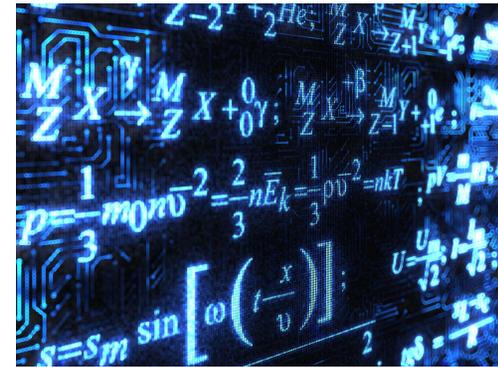
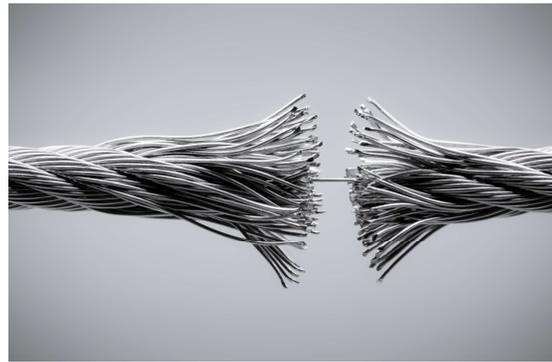
# In-use asset monitoring

- Maintenance of remote and large scale assets is expensive and the current asset state is often poorly understood.
- How can we combine measurement and simulation to better understand asset status and maintenance needs?



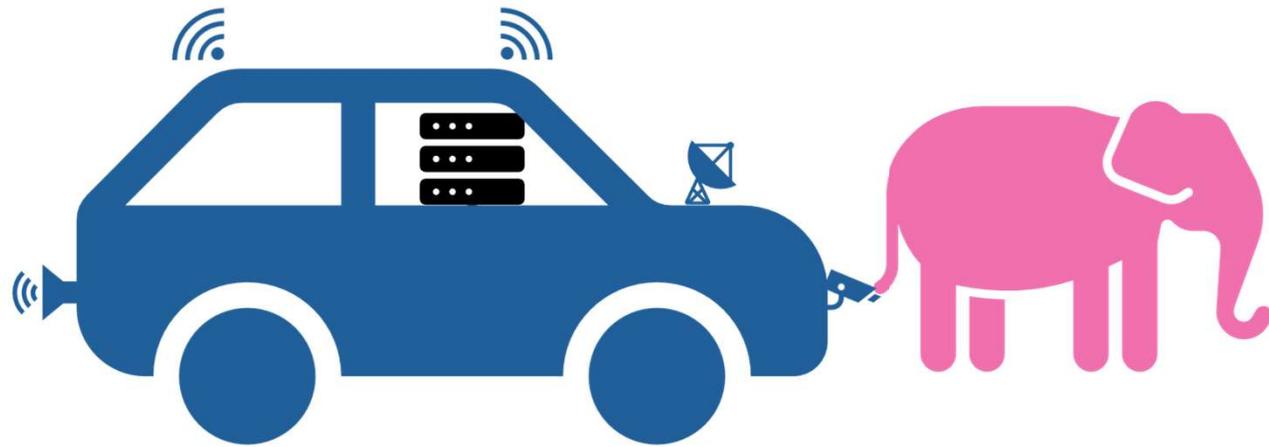
# More efficient product approval

- Physical testing takes time, costs money, and consumes materials.
- Can we combine data from physical testing and simulation to demonstrate product safety during approval processes more quickly and at lower cost?



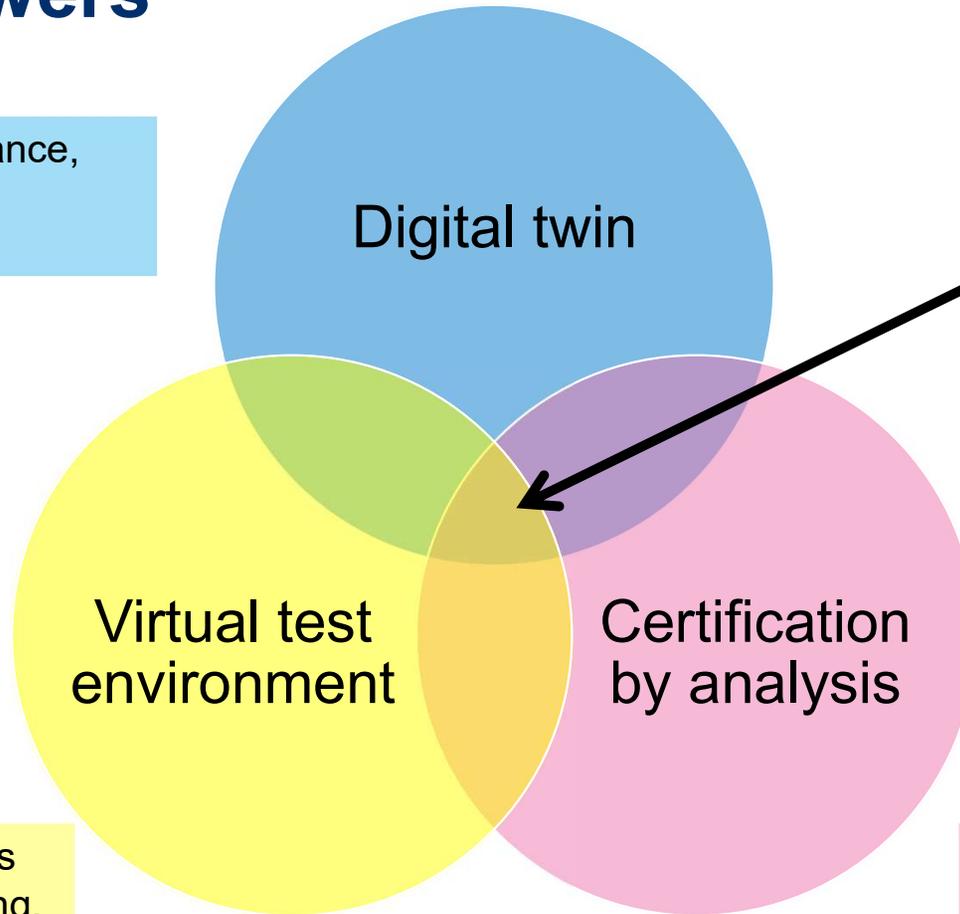
# Autonomous vehicles

- AI doesn't have "common sense" and only "knows" what it's "seen".
- How can we ensure autonomous vehicles operate safely when rare events happen?



# Possible answers

Asset monitoring & maintenance, lifetime prediction, situation management



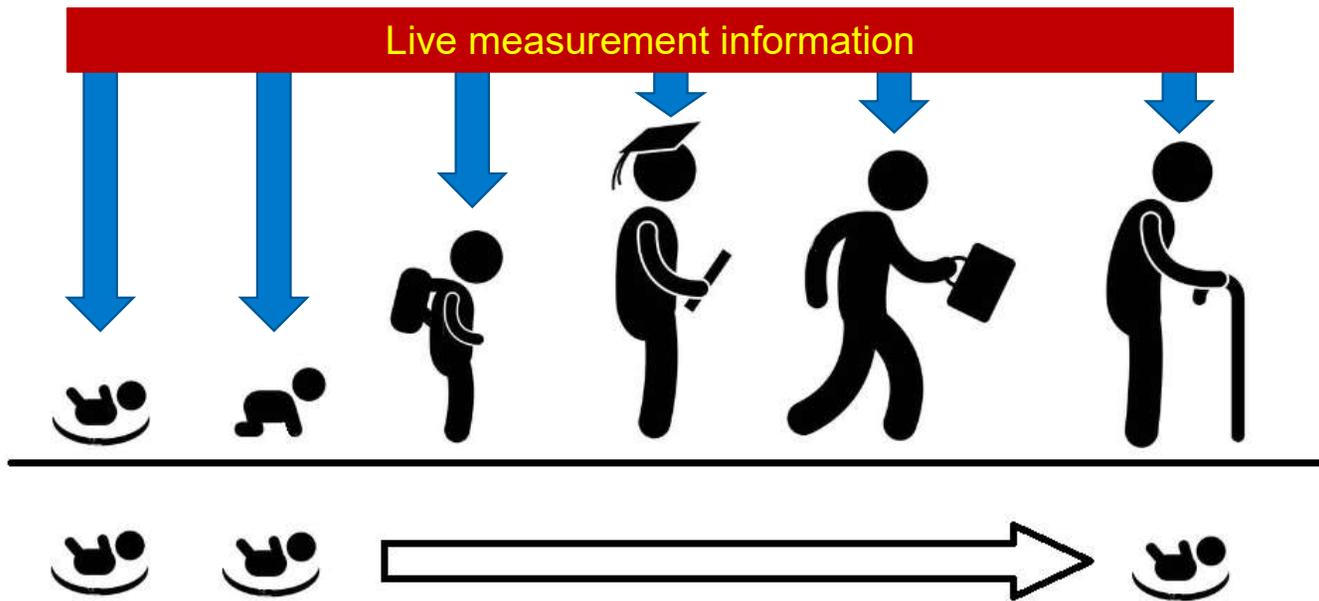
Measurement data and mathematical models

Testing of autonomous systems, virtual training, scenario exploration

Product approval, adaptive testing, design exploration.

# Digital twin

- Digital twin uses data from the real-world instance to create an accurate virtual representation of the current state of a system.
- Enables us to estimate what cannot be measured directly and make predictions and decisions based on best belief of current state.

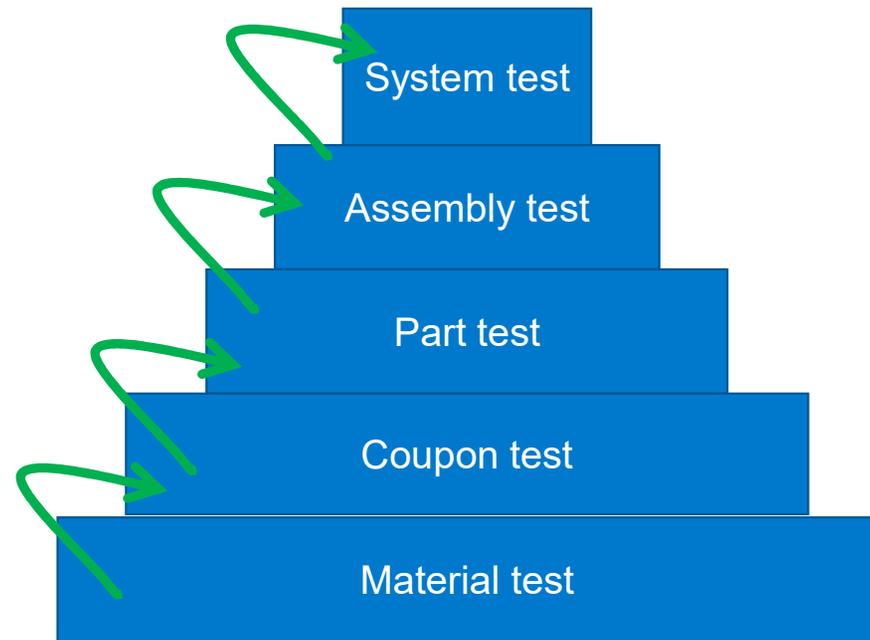


Digital twin reflects current device state

Model remains the same throughout device lifetime

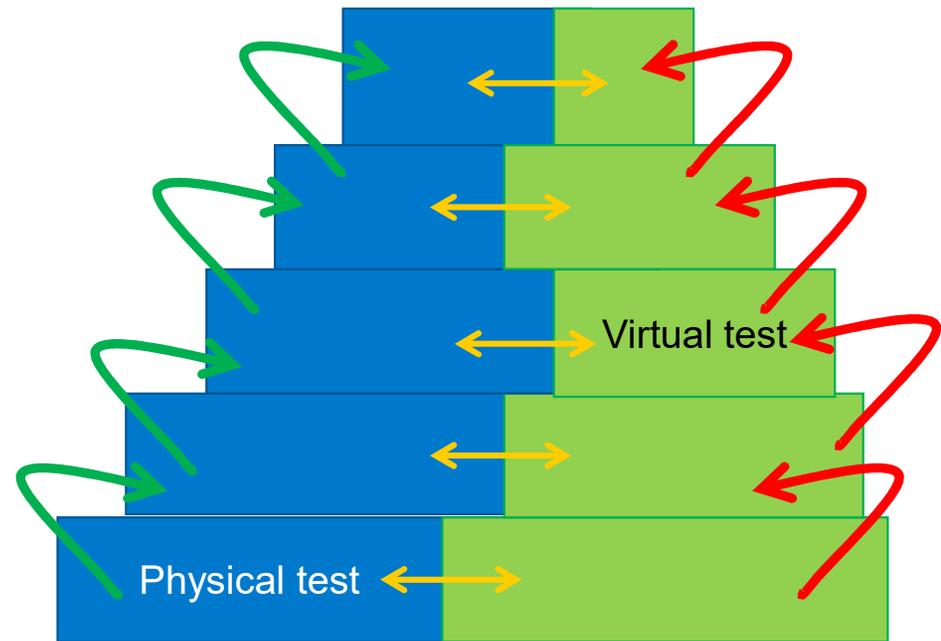
# Testing pyramid

- Multi-component systems may require multi-level testing to provide evidence for certification.
- Medical devices may require extensive clinical trials to capture population characteristics adequately.



# Testing pyramid

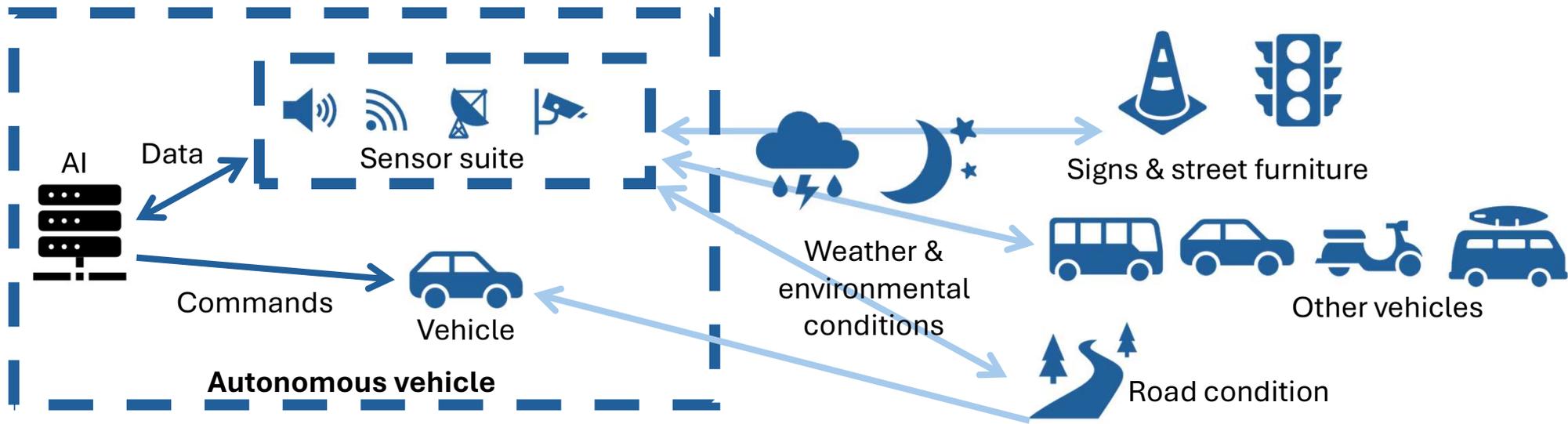
- Multi-component systems may require multi-level testing to provide evidence for certification.
- Medical devices may require extensive clinical trials to capture population characteristics adequately.
- Virtual testing with validated high-fidelity models could be quicker, cheaper and potentially more informative.



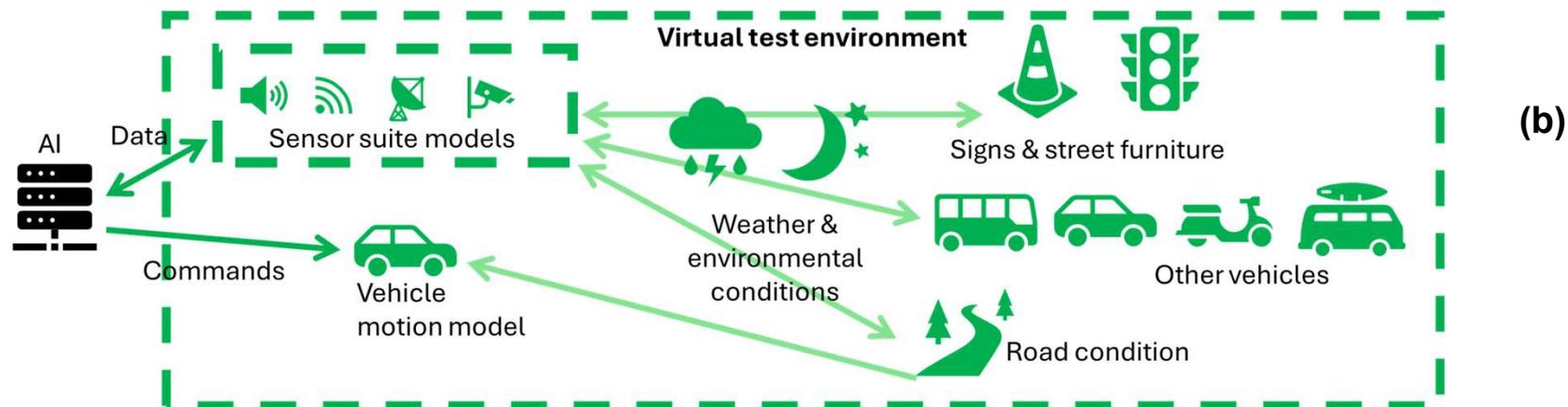
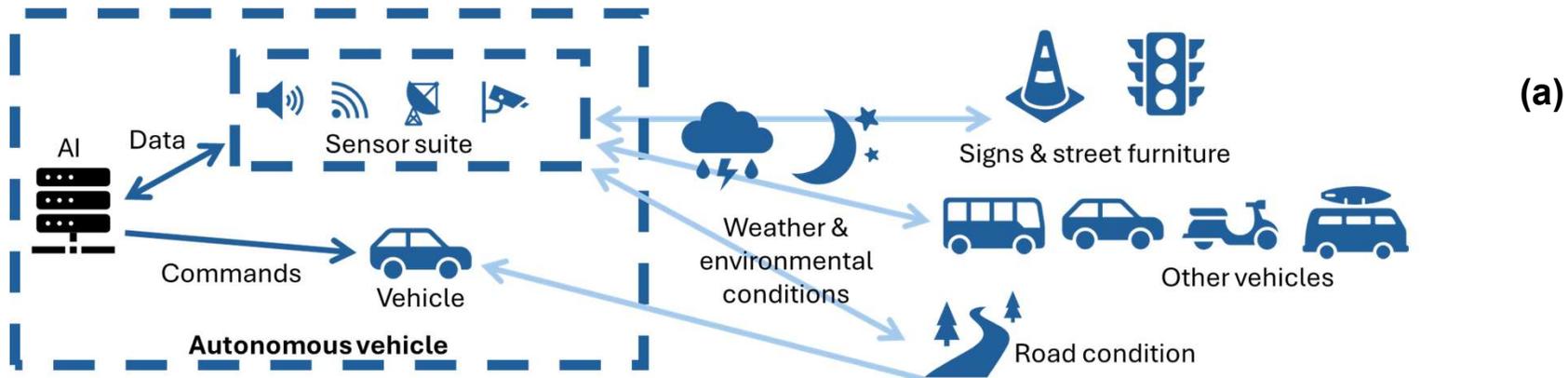
# Virtual testing environment

- Need virtual testing environments (VTEs) to carry out tests that are potentially dangerous or involve rare events.
- These do not need to be digital twins.
  - Accurate reflection of the current state of a place is less important than realistic simulation of the test situation.
  - Some applications benefit from having a virtual equivalent of a real-world environment, but in many cases no need to base them on real places.
- Worth thinking about what is needed in a bit more depth.

# What affects an autonomous vehicle?



# Needs to be translated into a VTE

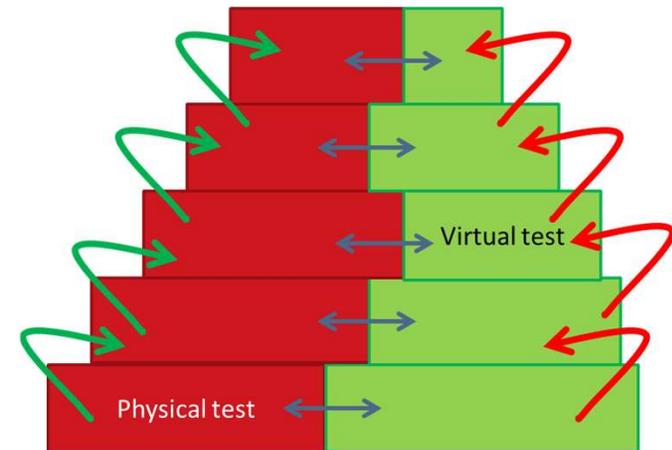
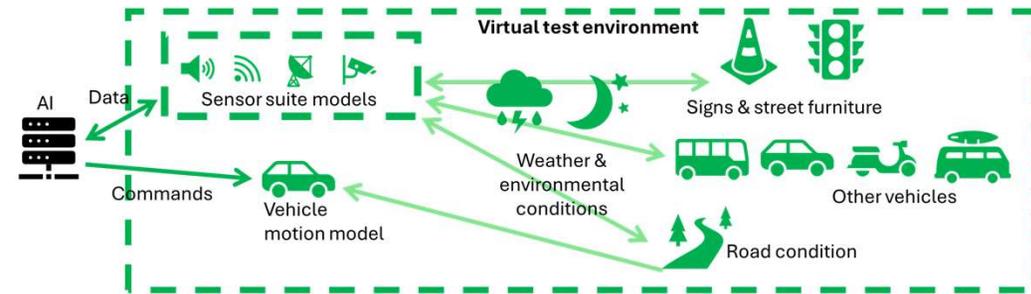


## VTE: Users & requirements

- Certification bodies can assess vehicles.
- Developers can rapidly explore conditions in new potential markets.
- Needs to go beyond photorealism: radar & lidar need appropriate properties for objects in the VTE.
- Weather needs to be described and parameterised.
- How do we define a test comprehensively but manageably?
- Real world → random → uncertainty is key.

# What links them?

- Measurement data plays a key role.
- Need for real-world fidelity.
  - “Real-world” includes underlying physics **and** natural variability.
- Complexity.
  - Influence factors and effects.
  - Multi-actor multi-physics systems.
  - Multiple data flows.
  - Cumulative approach to evidence.
  - Effects that are difficult to quantify.
- Need for acceptance & trust by multiple stakeholders.



# Fidelity

- Methods & frameworks for validation, verification and uncertainty quantification of physics-based models are already well-established.
- Not always known what to put into the frameworks however.
  - Uncertainty and data quality assessment are not common considerations to some engineers.
  - Training & tools can help.
- Demonstrating and checking fidelity may be time-consuming.
  - Not just about the model accuracy: input data quality, model scope.
  - Automated data quality checking will make things more efficient.

# Complexity

- Managing complexity is probably better than trying to reduce/remove it.
- Management of complex models requires
  - Validation of individual components (inc. environment).
  - Validation of interactions between components (inc. environment).
  - Checking for emergent behaviour.
- Management of complex data flows requires:
  - Standardised vocabularies & interfaces
  - Semantic links between data (e.g. use of ontology)

# Trust

- Trust requirements vary with context, person, and end use.
- Metrology creates trust in measurement data via traceability back to an agreed definition.
- Overall trust in complex application often needs:
  - a more careful definition of what an individual test or model is testing or describing.
  - a large suite of tests to answer multiple questions.
- Careful statements benefit from standardised vocabularies.

# Stakeholders

- Variation in expertise, technical language and priorities.
  - Different aspects of trust need emphasising.
  - Presentation of results needs to be in their preferred form.
  - Standardised vocabulary if possible, thesaurus to “translate” terms if not.
- Potential knowledge gaps, particularly around simulation and interpretation of uncertainty.
  - Tools that automate unfamiliar processes and present results in an interpretable way.
  - Examples for people to “play with” uncertainty evaluation that are relevant for their work.

## “In silico” testing: CEiRSI

- [UK Centre of Excellence in In-Silico Regulatory Science](#)
- Collaboration between academia, regulators, research bodies, sector bodies, software suppliers and companies.
- Focussed on medical device applications.
- Seeking to establish frameworks that can get computational model results accepted as evidence in regulatory processes.
  - Potential to reduce medical trial size & duration and to address edge cases directly.

**Key  
session**



## Airlock Panel Session - In-Silico Trials of TAVI Devices: Blood Flow Models Predicting Aortic Stresses and Valve Leakage

Wednesday 19<sup>th</sup> November | 14:00–16:00 (GMT)

### Leads:



**Martha De Cunha Maluf-Burgman**  
Director Regulatory Affairs,  
Edwards Lifesciences  
Policy Development WG,  
Avicenna Alliance



**Dr Ali Sarrami**  
Lecturer in Cardiovascular  
Biomechanics,  
University of Manchester



**Dr Yidan Xue**  
Research Associate,  
University of Manchester

### Panellists:



**Dr Adesola Ademiloye**  
Programme Director,  
Swansea University



**Dr René Bombien**  
Clinical Director,  
qtec services



**Mark Grumbridge**  
Head of Clinical Investigations,  
MHRA



**Alexander McLaren**  
Benefit Risk Assessor,  
MHRA



**Dr Cahal McVeigh**  
Research Director, Global  
Technology & Innovation,  
Medtronic



**Dr Pawan Kumar Pandey**  
Research Associate,  
University of Manchester



**Dr Steven Kreuzer**  
Senior Managing Engineer,  
Exponent

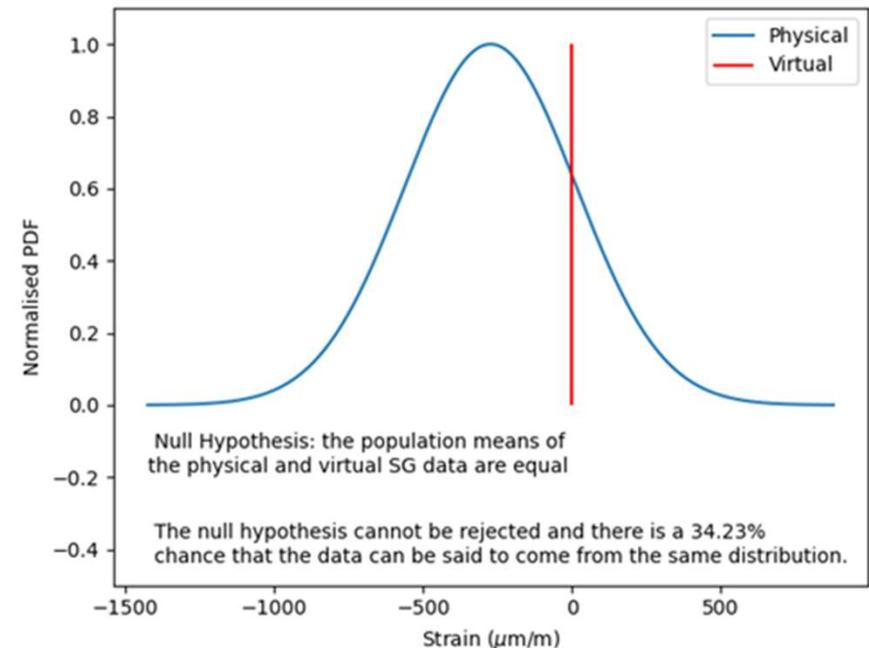
# Smarter Testing project

- Airbus, NPL, Dassault Systèmes, CFMS, and Zeiss, Contract: D20016286.
- Project developing tools and a platform to make best use of measurement data from tests and simulation results to include simulation in the test pyramid.
- NPL role: ontology development, measurement techniques, uncertainty evaluation tools.
- Uncertainty evaluation focus was on “point” measurements
  - Strain gauges, force transducers, ...
  - Others working on “full field” e.g. digital image correlation



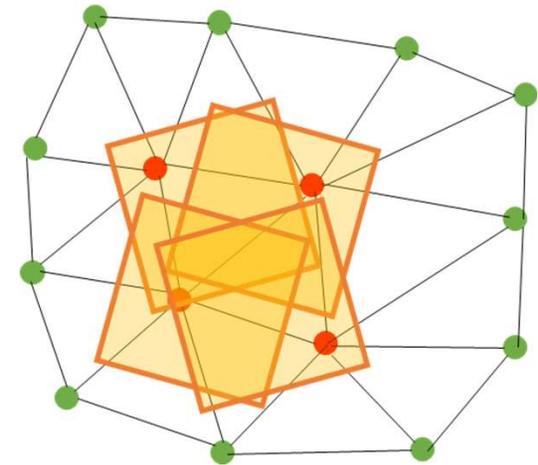
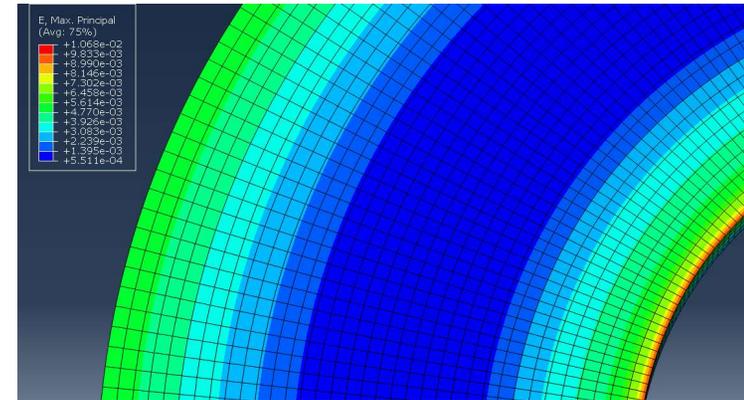
# Uncertainty evaluation tools

- Three tools developed addressing different needs of the engineers:
  - Hypothesis testing for comparison of data sets.
  - Strain gauge placement uncertainty evaluation tool.
  - Input uncertainty propagation to simulation results: walkthrough example.
- Tools work within existing engineering workflows.
- Hypothesis testing tool provides a quantitative level of confidence in the agreement between data sets (e.g. for validation).
- Can include uncertainties associated with one set or both.



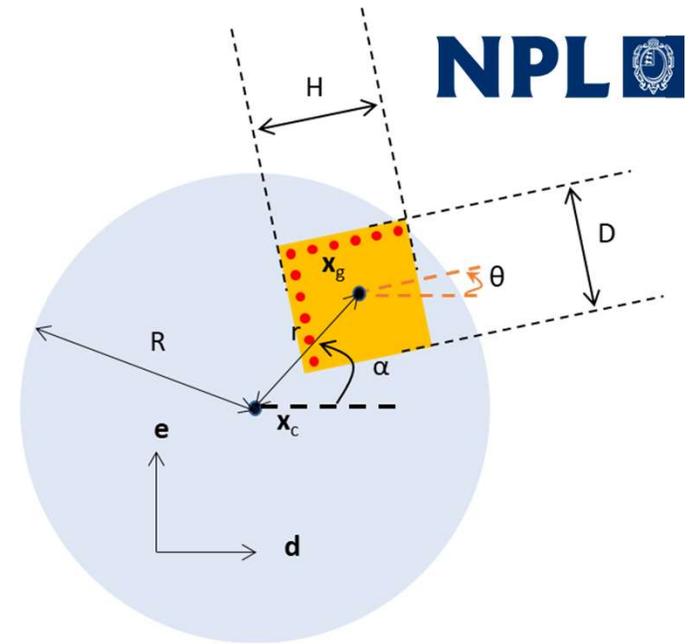
# Strain gauge misplacement & misalignment

- Strain gauges measure local strain during testing relative to a nominal set of axes.
- Results are affected by placement and alignment.
  - Characterise by offset & rotation.
- Strain is calculated by finite element models.
- Tool post-processes finite element model results to estimate uncertainty contribution from misplacement & misalignment.

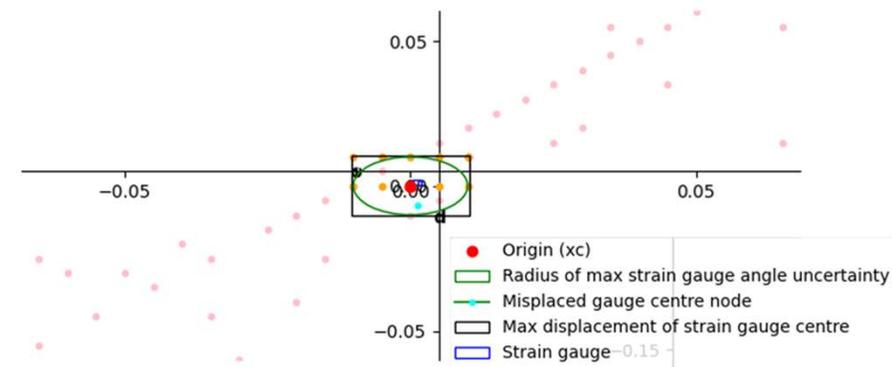


# Strain gauge approach

- Identify nodes that are close to the strain gauge.
- Construct a local approximation model for strain that interpolates nodal FE results.
- Sample from the offset & rotation distributions.
- Calculate the coordinates of a grid of points within the sampled gauge position.
- Use the patch model to evaluate the strain at the points and average.
- Repeat for more samples.

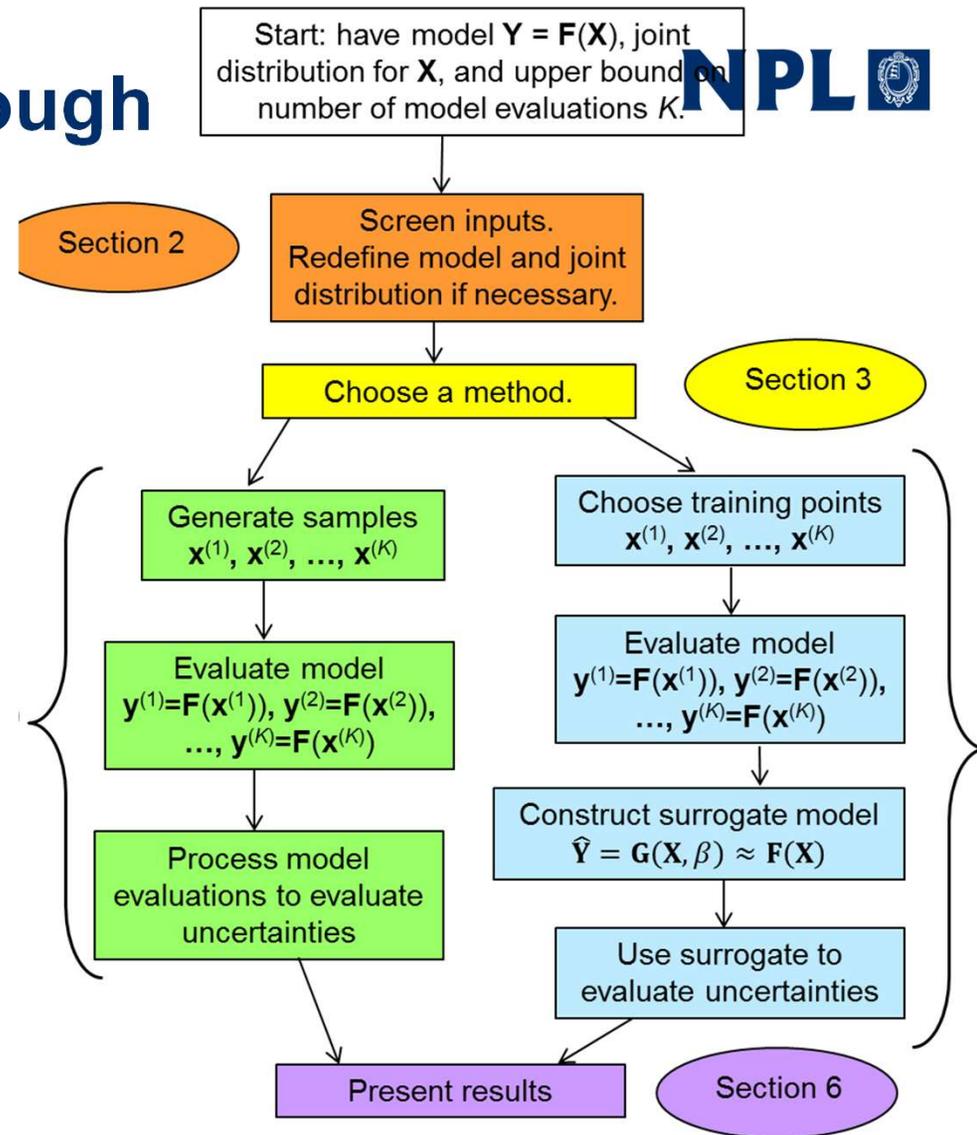


Local plot of nodes the strain gauge may cover for  $x_c$  global [0.145 0.02508648 0.01 ].



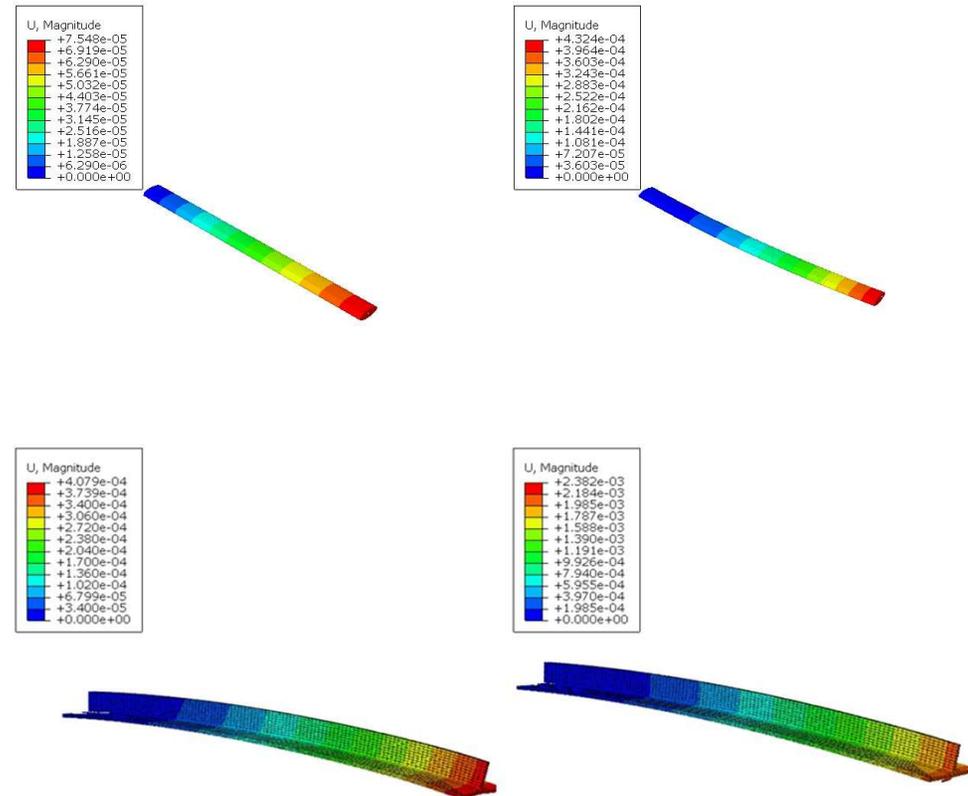
# Uncertainty propagation through finite element models

- FE models are often computationally expensive.
- Previous EMPIR project produced good practice for UQ for comp exp models.
- Sensitivity analysis to focus the input space.
- Latin hypercube sampling for better results from a small sample size.



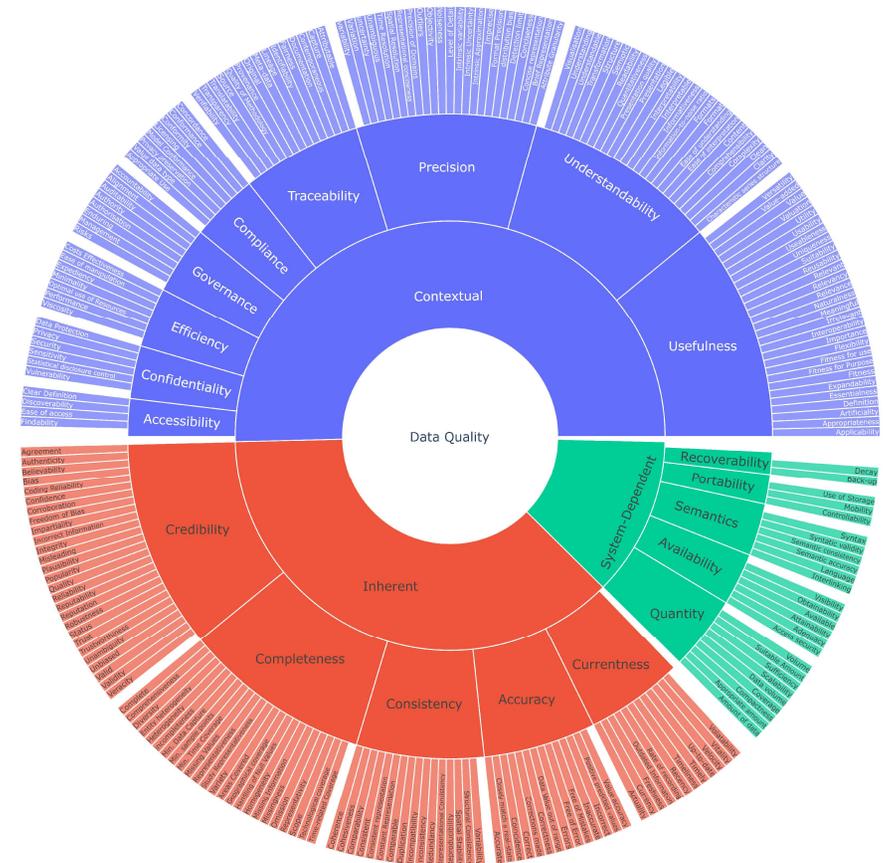
# UQ walkthrough example

- Simple test case of a beam under load.
- Python scripting with Abaqus to sample, build and run models, collect results.
- Document with examples of changes so that user understands what to do, why, and how to interpret and use the results.



# Data quality

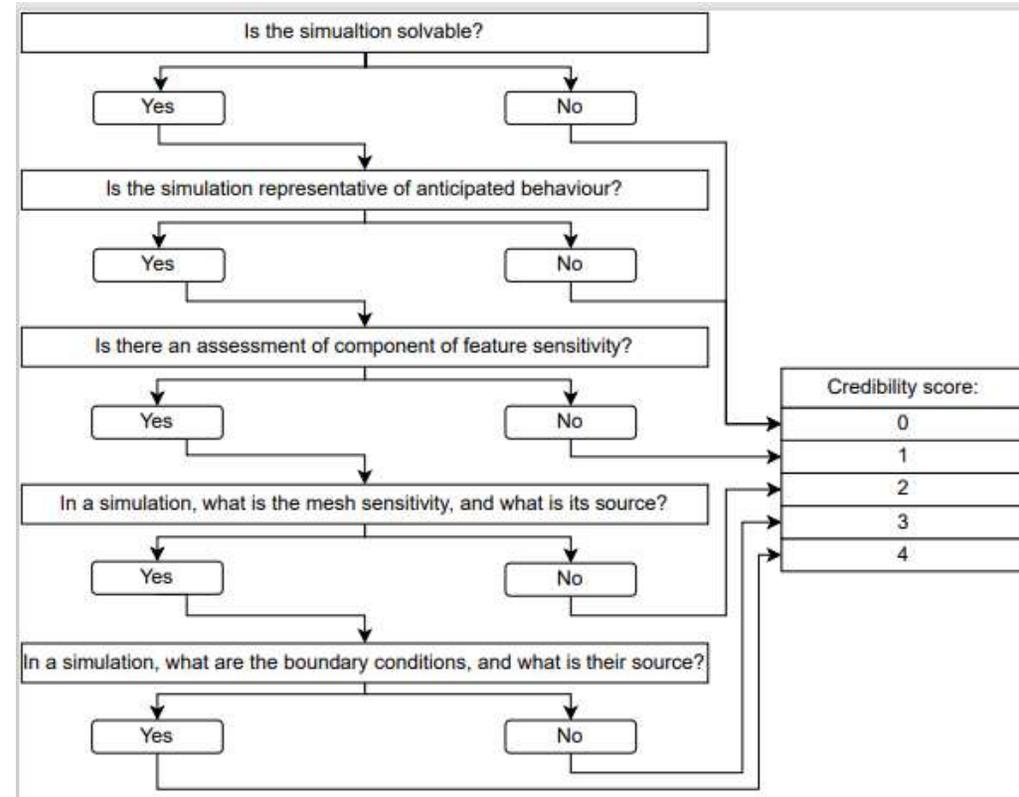
- The extent to which data has characteristics that make it suitable for a specific purpose
- Not one single thing: multiple dimensions, application drives which matter most.
- Data quality assessment requires definition of dimensions, metrics and acceptable evidence.



Source: <https://doi.org/10.3390/data9120151>

# Automated data quality checking

- Data credibility frameworks can be built by
  - identifying evidence of credibility,
  - linking sources in a queryable data model via semantic technologies.
- Standardisation for a given type of approval would be part of bridging the skills gap and speeding up the process.

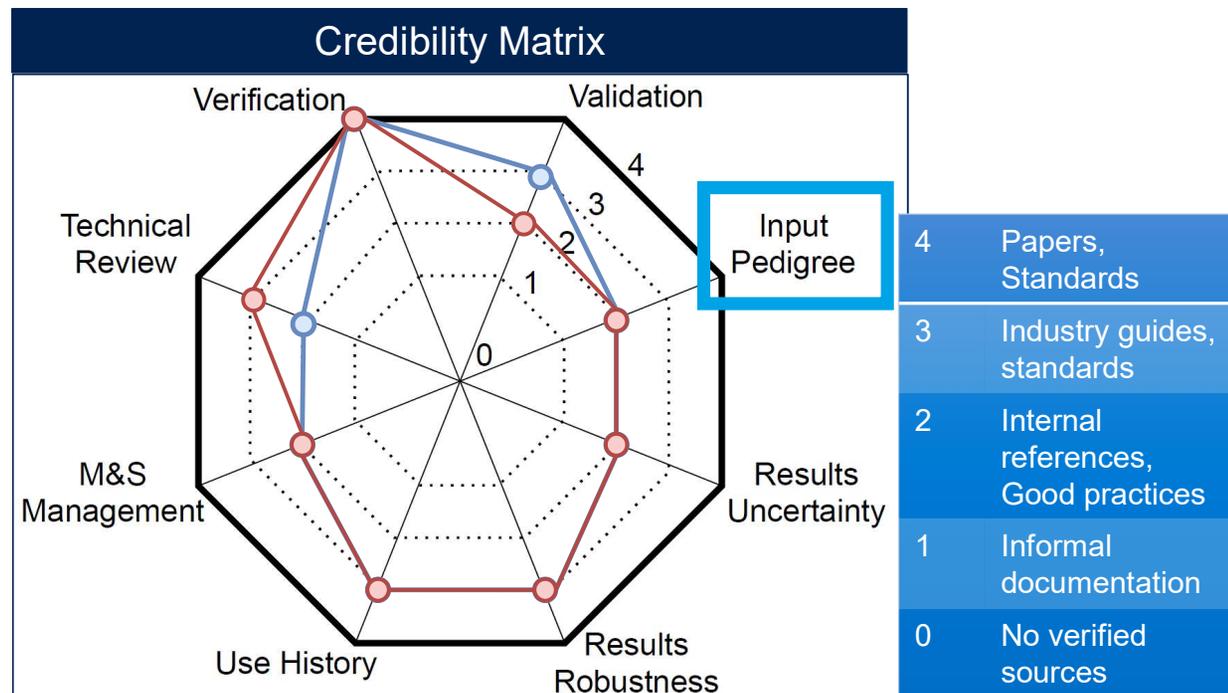


# Model credibility: the ReMake project



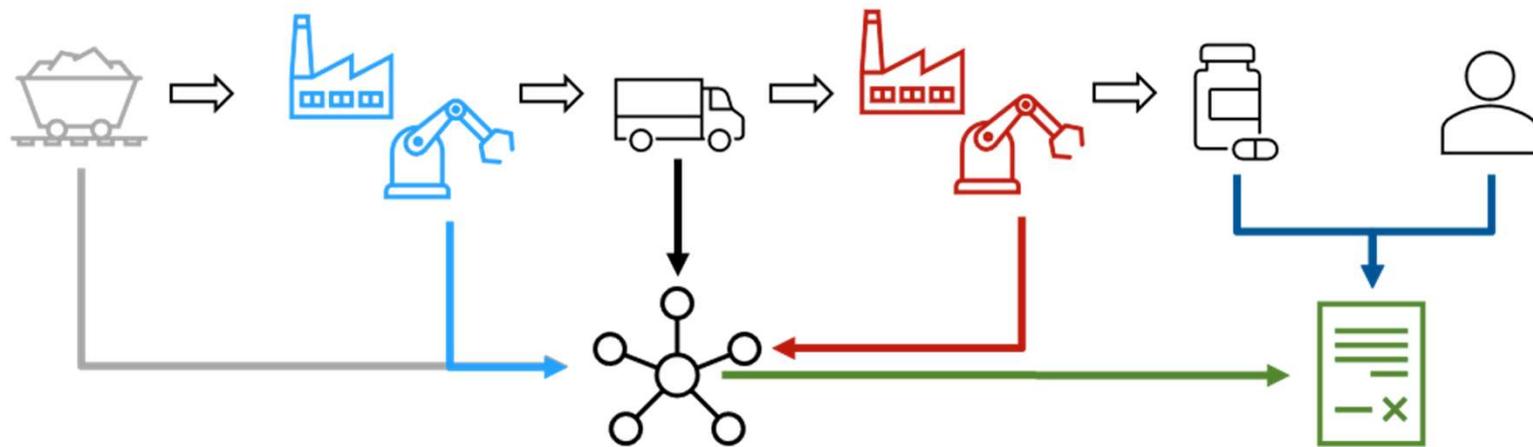
NMIS  
National Manufacturing  
Institute Scotland

- Collaboration between NPL and NMIS.
- Use models to predict outcome of reworking components.
- Used an automated approach to developing model credibility to support trust.



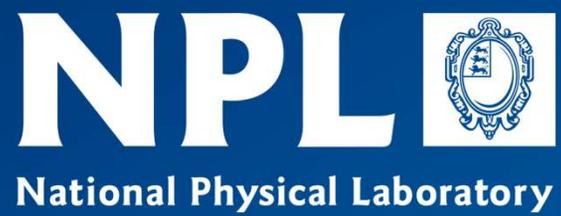
# Semantic technologies

- Semantic technologies can support reducing time taken for approval processes by automating routine checks.
- Worked with pharmaceutical manufacturers to capture expert knowledge as an ontology and use to enable qualified person to focus on parts requiring thought.



# Conclusions

- New ways of using simulation technology are leading to models of complex systems that require high levels of trust.
- “Trust” is built from trust in:
  - well-defined question, [input] data, models/algorithms, solution techniques, uncertainty evaluation, ...
- “Complexity” is best managed via standardisation of:
  - vocabulary, metadata, interfaces, quality metrics, (simulation) data management, ...
- Variety of stakeholders means communication flexibility is key.
- Bodies in many sectors have well-established guidance on some aspects already.
- Tools and automation, along with training, support uptake.



[npl.co.uk](http://npl.co.uk)