NPL
National Physical Laboratory

How digitalisation might support CCM's areas of interest

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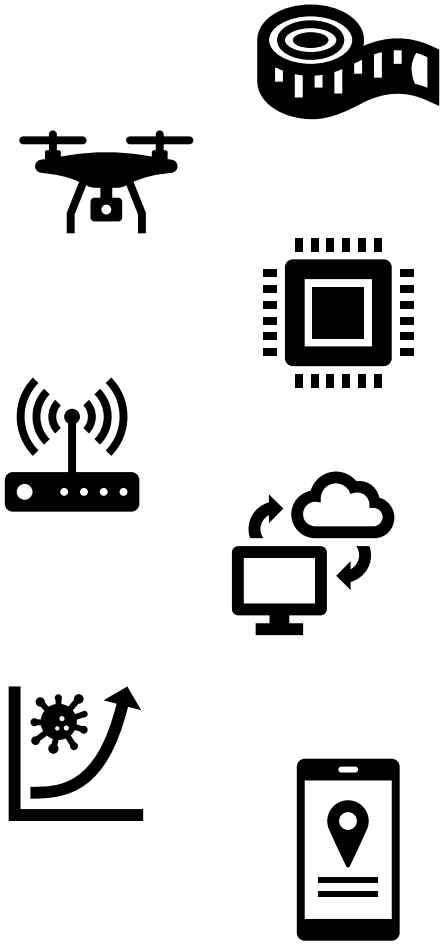
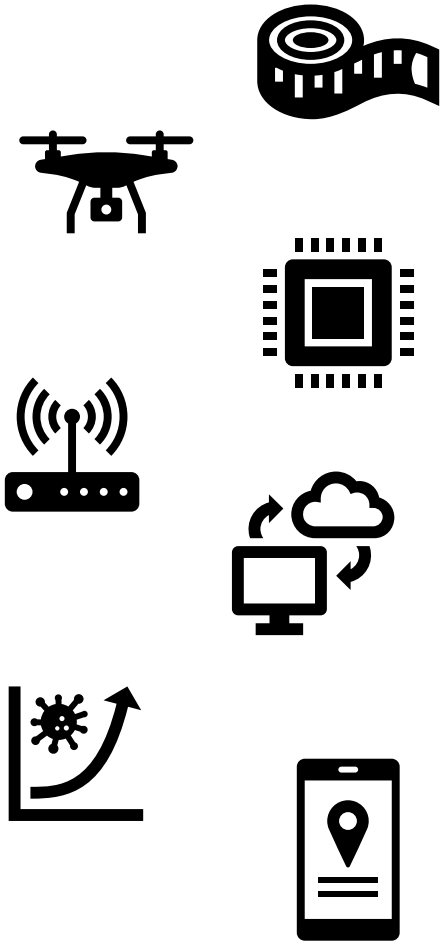
Digitalisation: definition and enablers

- Use of digital sensors, algorithms and computers
  - Not a new thing in itself
- Becoming more widespread because:
  - Sensors got cheaper and more reliable
  - Computational power got cheaper and smaller
  - WiFi got more reliable and faster
  - Data storage methods got more flexible
  - Data-driven analysis methods got more advanced
  - Everyone has a phone/laptop/tablet



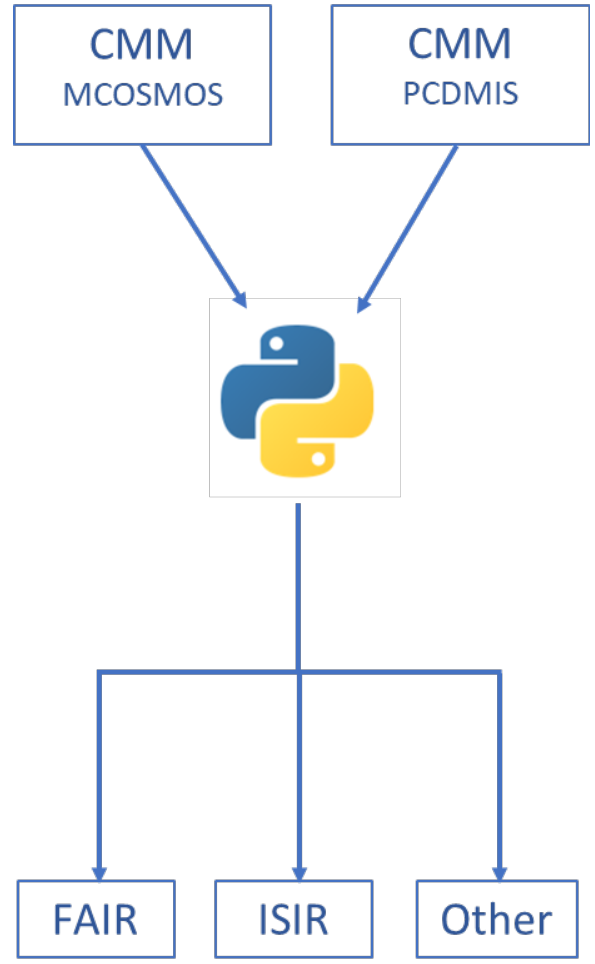
Digitalisation

- Most of our customers and end users are digitalising their processes
- This talk will focus on NMI-specific activities
- Will not talk about:
  - Digitisation vs digitalisation vs digital transformation
    - Short answer: data vs processes vs cultural change
  - Artificial intelligence and machine learning
  - Robotics
  - Data security and secure data transfer/sharing
    - E.g. electronic signatures, blockchain, …

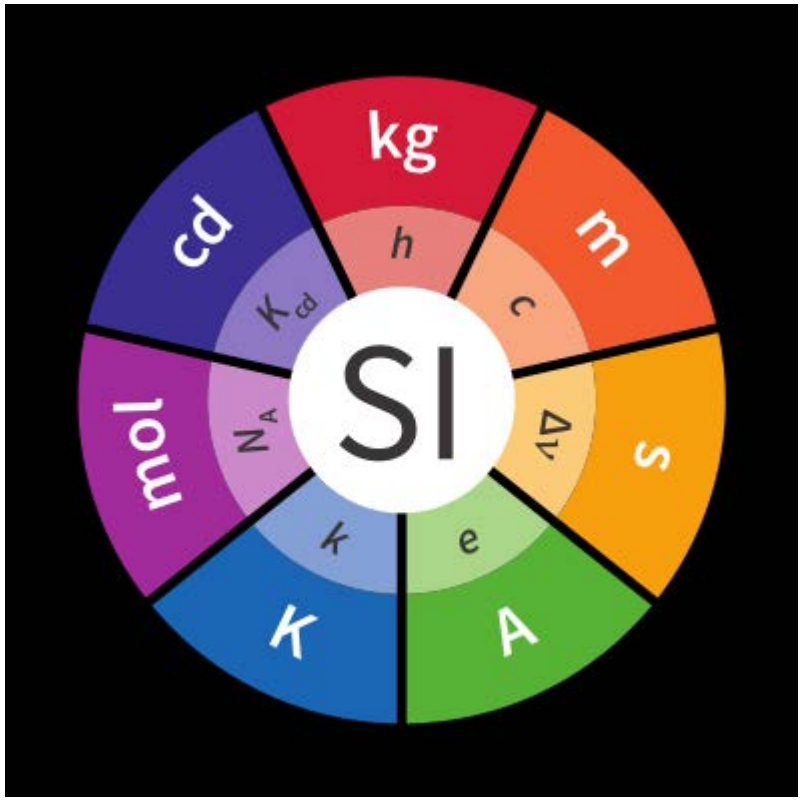


Activities, benefits, costs

- Covers a wide range of activities for NMIs
  - Automation of data generation, capture, analysis, storage, reporting…
  - Digital delivery: DCCs, interactive display, on-demand software & data access,…
  - Remote access & action: remote calibration, monitoring of in situ realisation, remote-controlled experiments…
  - Advanced analytics
- Frees up skilled staff, reduces error rates
- Implementation cost can be largely skills rather than software licences or large scale facilities



Opportunities for metrology



- Good metrology enables confidence in data quality
  - Needs to be used more widely for digital data

- Improve data quality for digital data
- Support addressing the reproducibility crisis
- Help end users use data we generate more effectively
- Use digital approaches to support SI realisation in situ and remote calibration

- Some aspects need a coordinated response, some aspects can take place at NMI/DI level individually

Data quality

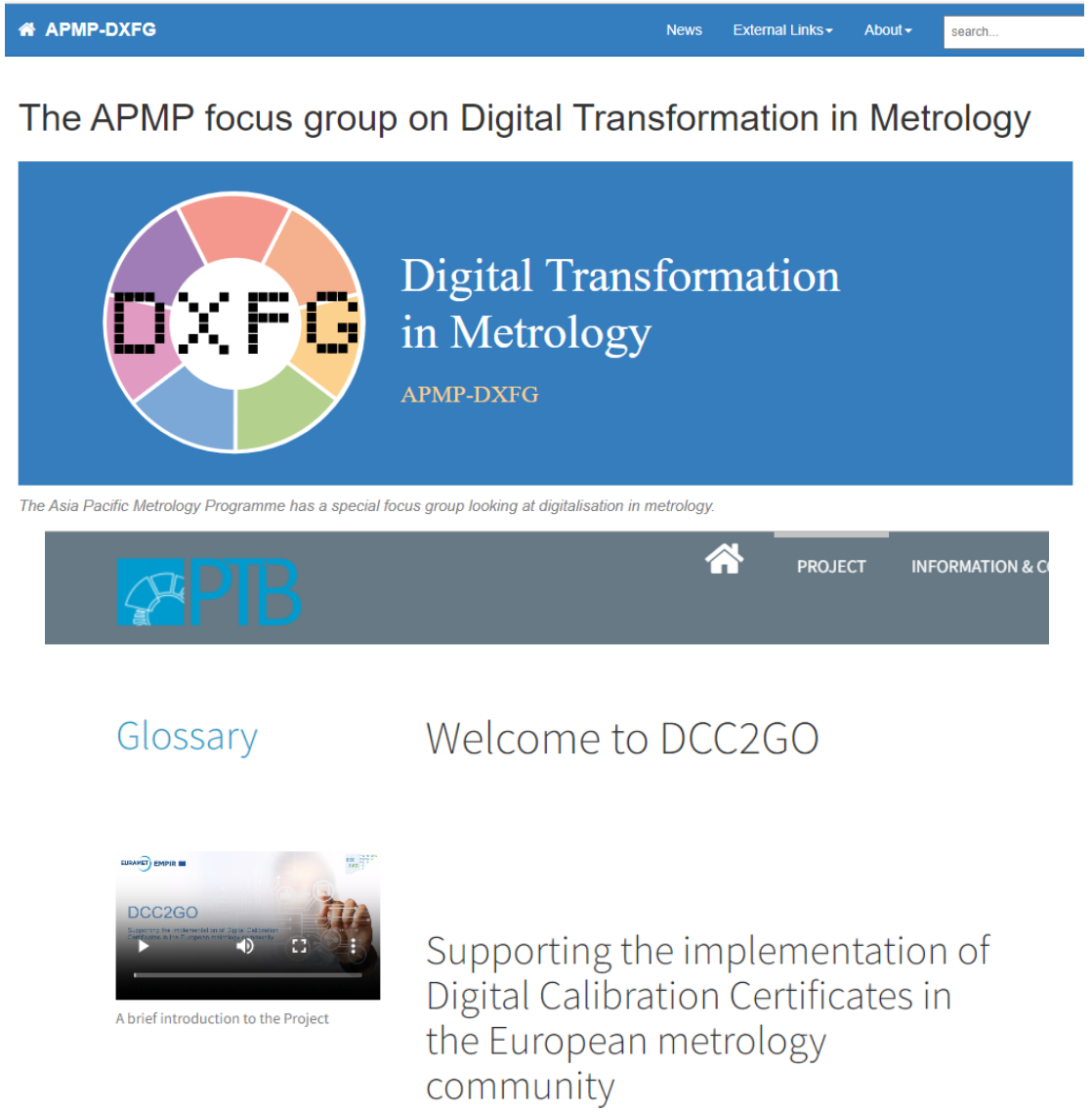
- Digital data is easy to capture, store and share
- However…
  - Easy to lose the contextual information that gives the data meaning (**metadata**)
  - Lack of standardised formats for data and metadata
    - Use of units in particular
  - Rare to see consideration of uncertainty in open repository datasets
  - Even rarer to see consideration of traceability or calibration directly associated with data
- These aspects improve quality and reusability of data

Metrology to enhance digital data quality

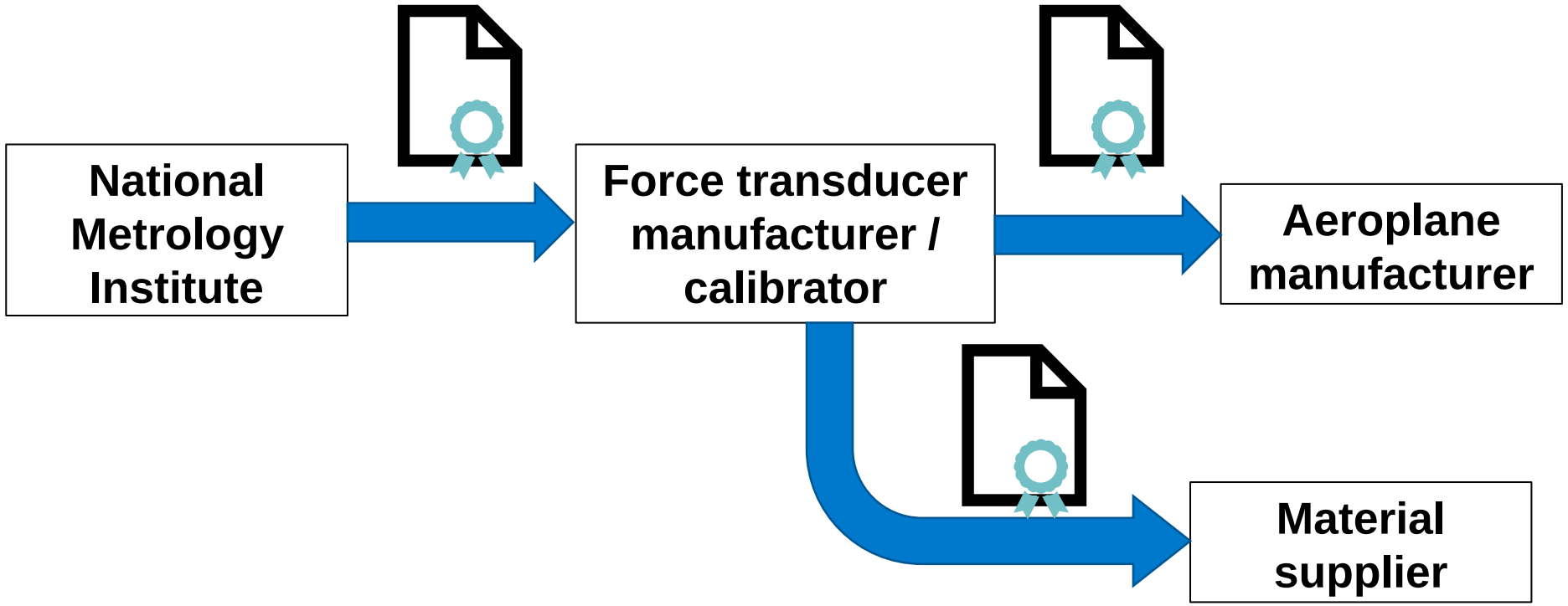
- Need to make it easy for people to include metrological information
  1. Digital representation of units that meets the needs of the SI
  2. Digital equivalent to a traceability chain right back to the SI definition
  3. Digital structure for uncertainty information
- BIPM projects are already addressing these points
- D-SI framework and digital calibration certificates support points 2 and 3
  - In particular, richer uncertainty information
- More complicated than this: provision does not guarantee uptake

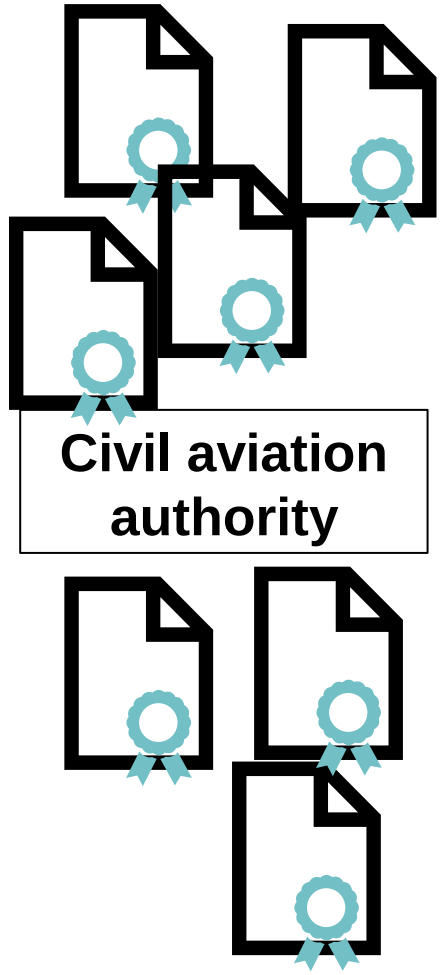
What needs to happen?

- A shared and transparent approach to digitalisation
- Benefits need to be clear and obvious: case studies will help with this
- Work with equipment & sensor manufacturers to embed D-SI in the output of their products
- Provide tools, training and guidance on how to get the most out of DCCs



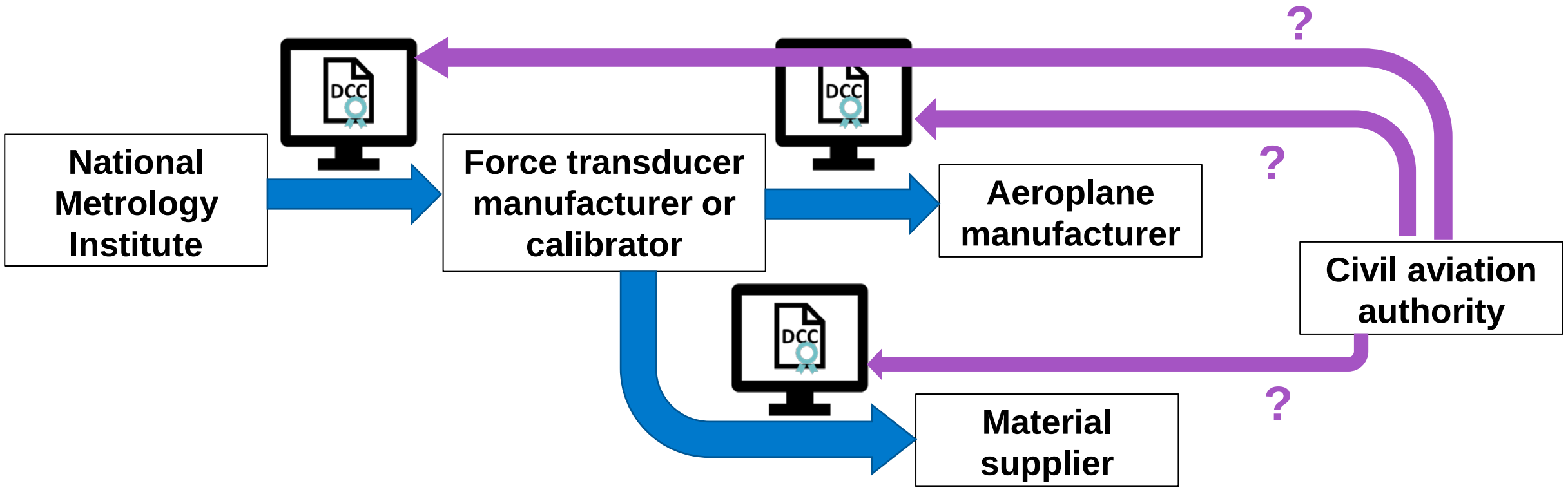
Example: supply chain auditing





- Safety critical industry may ask for complete supply chain calibration evidence
- Checking paperwork is time-consuming
- Likely to become more important as use of simulation replaces use of test

Example: supply chain auditing



- Digital certificates can automate some aspects of auditing
- Can query specific details without sharing the whole certificate
- Can go all the way back to CMCs if necessary

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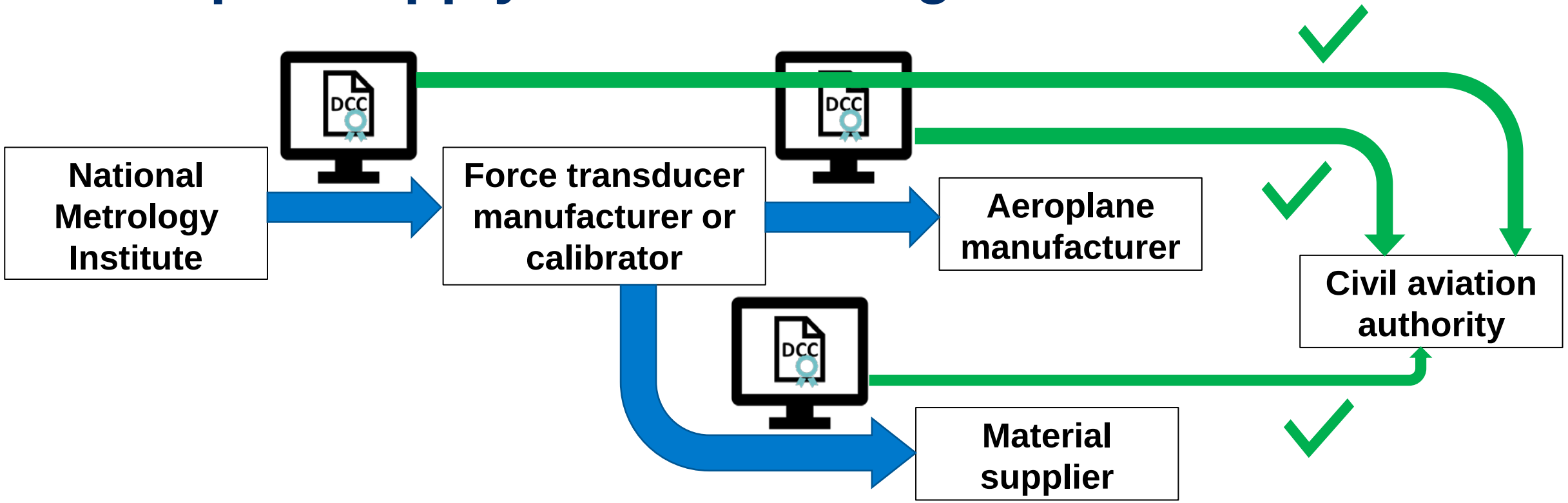

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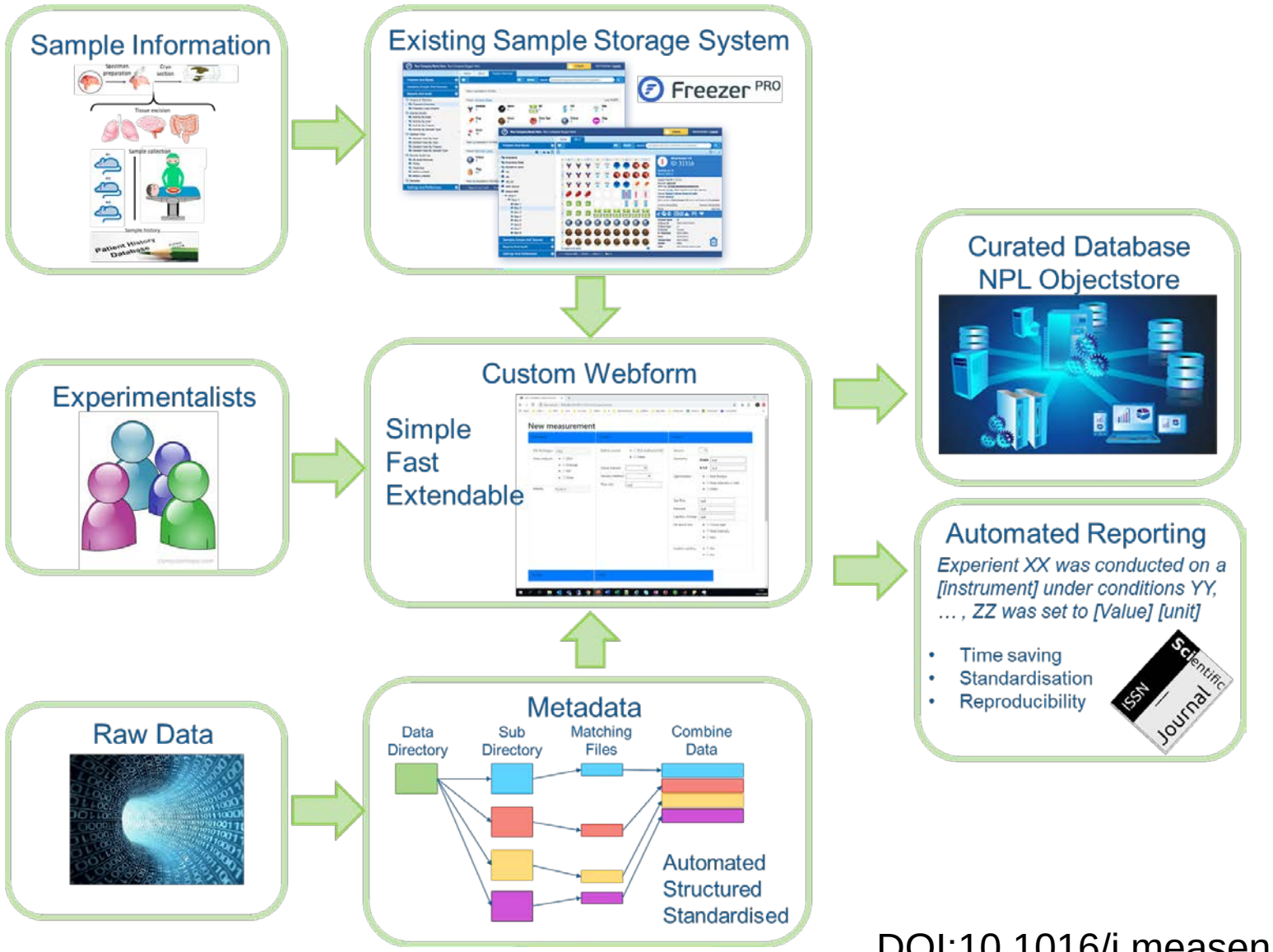
Reproducibility



- Metadata often gets left in lab books and separated from data
- Automated capture from equipment plus digital interface to generate standardised metadata linked to the data
- Create supplementary material for papers etc.
- Restricted vocabulary, could feed into ontology
- Additional analysis opportunities

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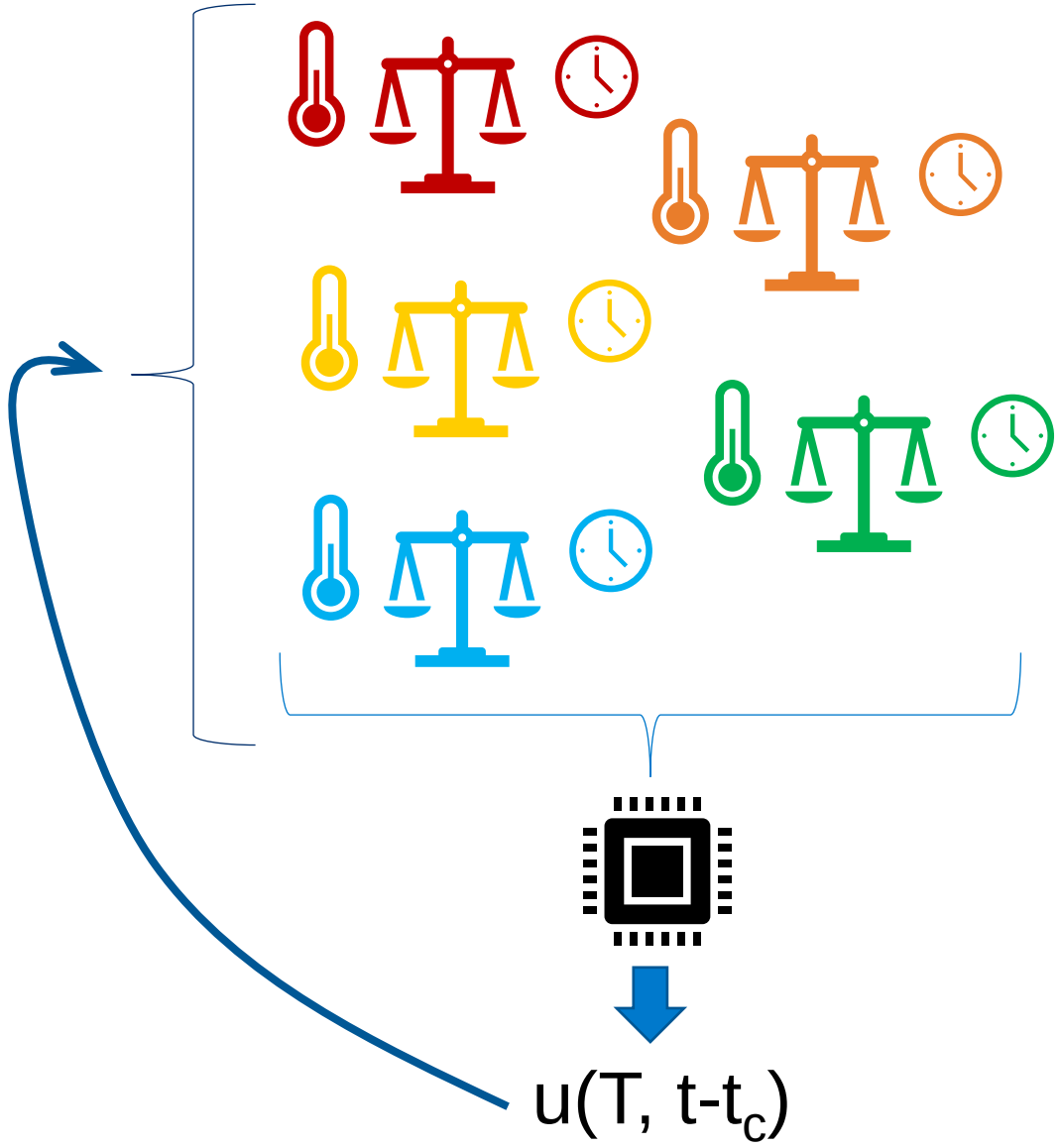
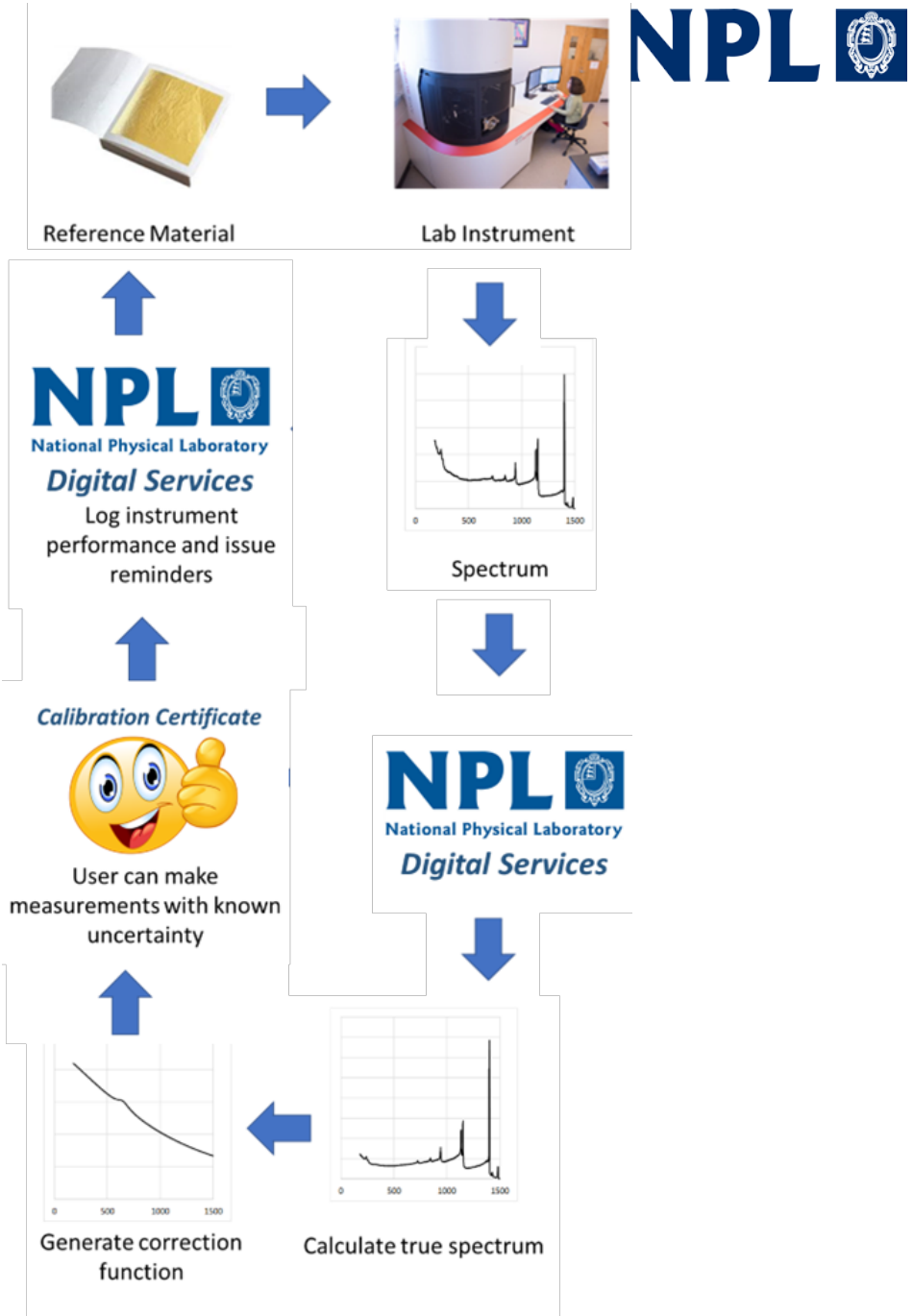
End users

- Smarter use of historical data
  - Assess the reproducibility of the calibration process using stable artefacts
  - Device health monitoring for repeat customers
  - Population and in operando data for manufacturers of widely-used kit to improve uncertainties
  - Potential to push updated uncertainty information back to devices
- Provision of data in application or sector-specific forms
- Software as a service & remote calibration



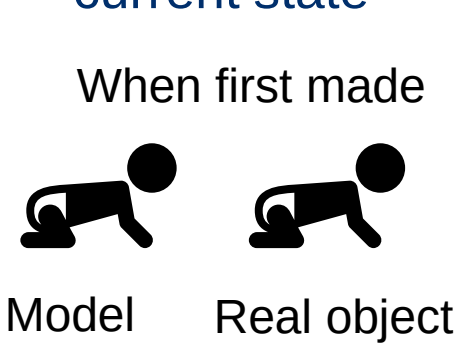
Remote calibration

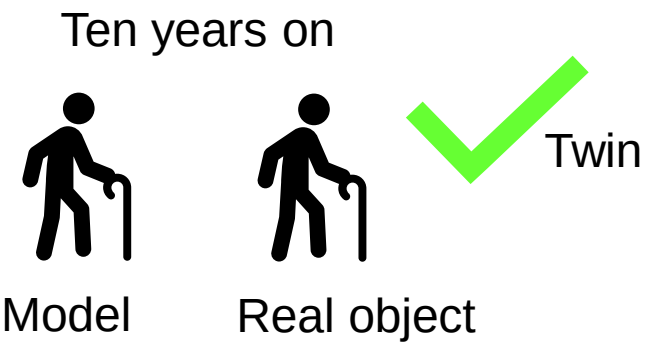
- Benefit: less down time for the equipment, potentially lower cost
- Need
  - a stable artefact with an appropriate level of uncertainty,
  - a simple well-documented procedure,
  - low “user-associated” uncertainty contributions, and
  - standardised outputs
- Demand may only be there if associated calculations are difficult

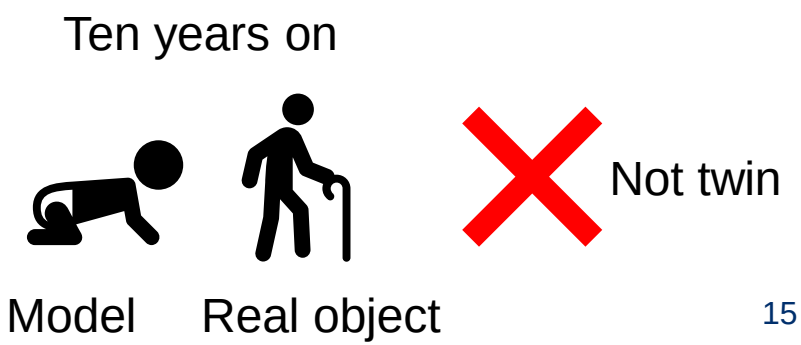


Realisation in situ

- Exciting developments for realisation in situ of various SI base units
- Shorter calibration chains, removal of some calibrations altogether
- Still need monitoring and validation
  - Realisation may not drift, systems that capture the data will
  - Users may require more confidence measures for acceptance
- Digital twin approach can provide monitoring and extra insight
  - Model: snapshot of an object (existing or not) that predicts an aspect of the object's behaviour
  - Digital twin: a model of a real object that is updated using data from the object to reflect its current state







Digital twin example

- Offshore windfarm with vibration sensors on the turbines and wind speed measurement
- Model that predicts vibration behaviour given wind speed and a bearing wear parameter
- Digital twin links the two to estimate wear parameter given the measured data
- Use to schedule maintenance effectively based on knowledge of current state

Digital twin for monitoring Kibble balance

Describe state we want to monitor with parameters

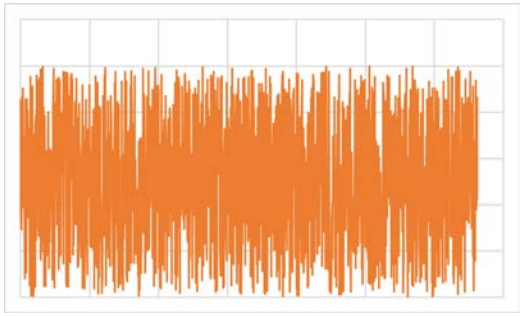
$\mathbf{a}$ in an appropriate model

Initial estimate of $\mathbf{a}$

$$Mg = I\left(\frac{\partial\phi}{\partial z} + f(t, z, \mathbf{x}; \mathbf{a})\right)$$

$$V = u\left(\frac{\partial\phi}{\partial z} + f(t, z, \mathbf{x}; \mathbf{a})\right)$$

Other parameters $\mathbf{x}$

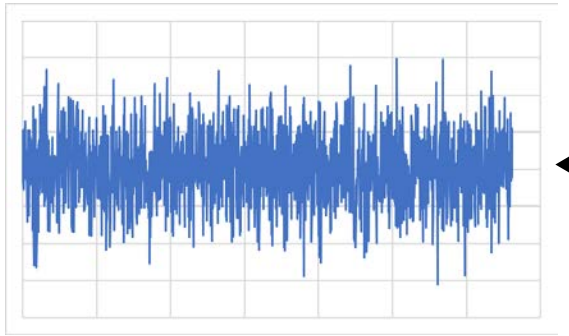


Model results

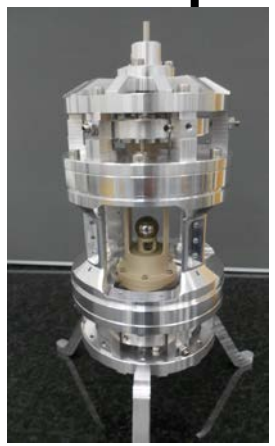
Track updated values of $\mathbf{a}$ to monitor object

Model updating process

New estimate of $\mathbf{a}$



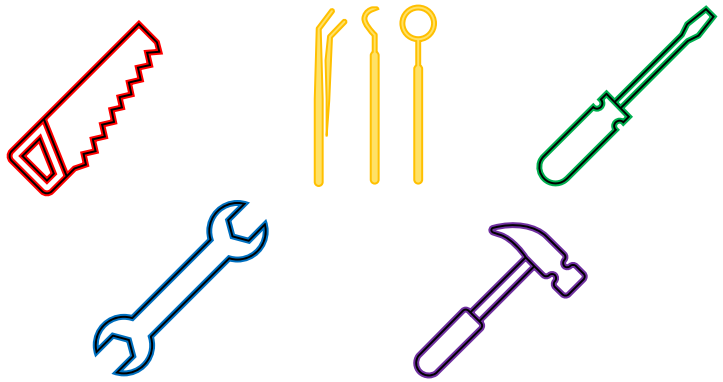
Real data



Act if parameter values indicate a problem

Closing thoughts

- Good metrology improves confidence in data
- Digitalisation offers opportunities to embed good metrology in more areas
  - BIPM already working on this
- In situ realisation may change role of NMIs
- Opportunities for NMIs to improve their own practices and to deliver more value to customers
- One more tool in the metrology toolbox



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