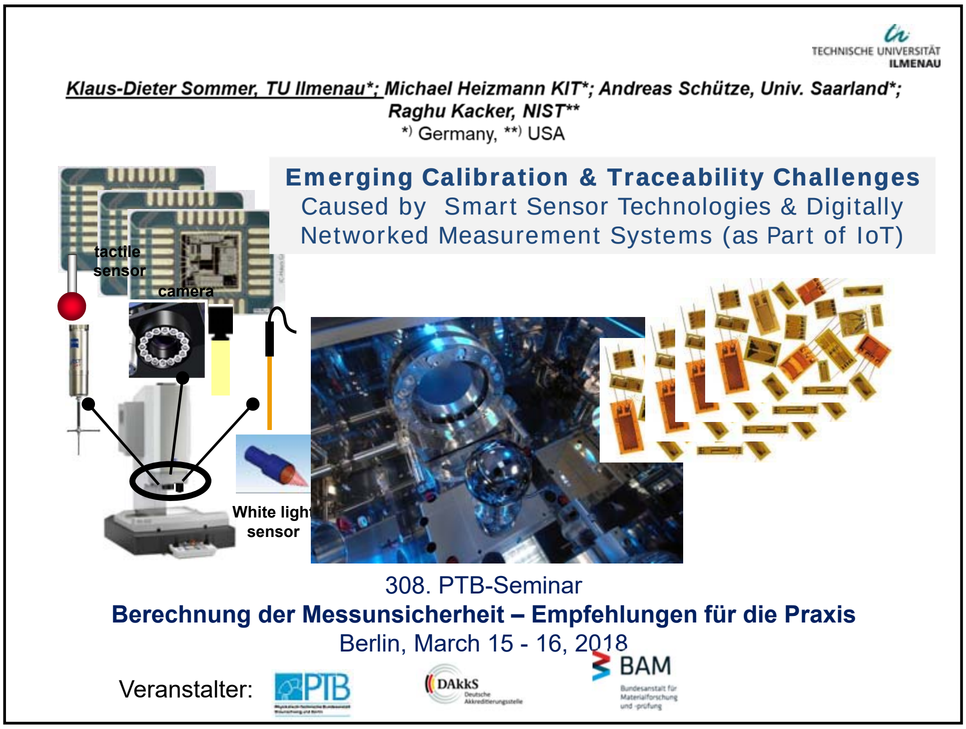
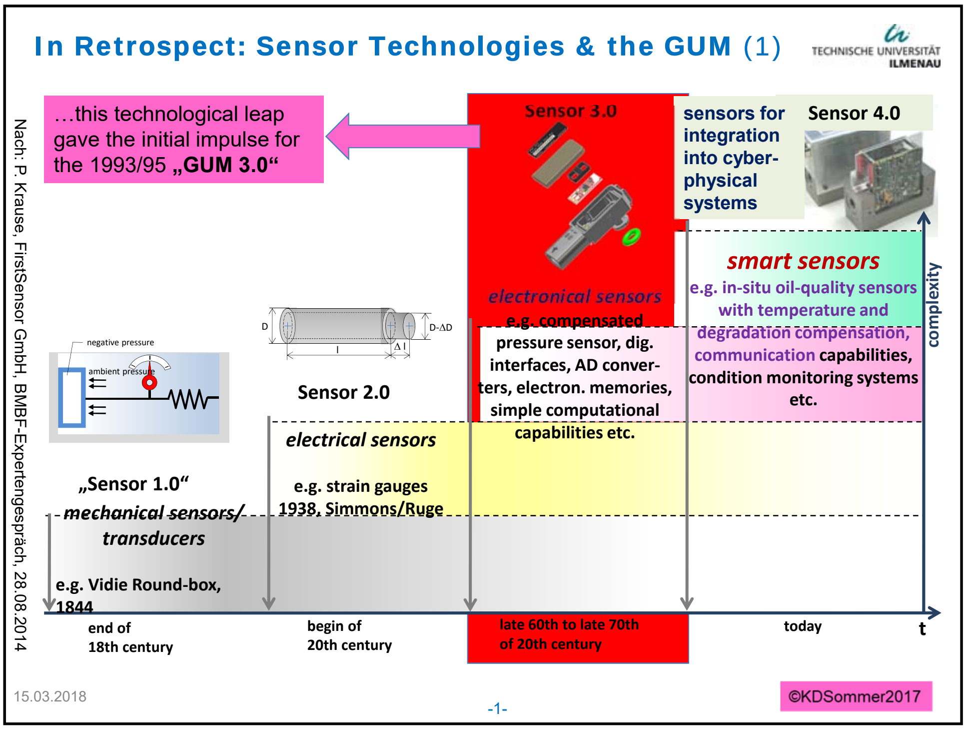
# Emerging Calibration & Traceability Challenges



# Emerging Calibration & Traceability Challenges

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## The Guide to the Expression of Uncertainty in Measurement

Result of the New Data-Evaluation Opportunities of the 60th/70th

A Review

**State-of-the Art of measurement evaluation up to the mid-80th:**

A Error Analysis with special **emphasis on random errors**
B **Systematic errors were seen as** principally **recognisable**, but …

**The technology leap 3.0 of the 60th/70th: New technological reality:**

C **Digital measurement-data processing** as well as **digital data storage**
D … therefore, **automatically repeated acquisition & computer-aided processing of measured data**

- consequently, **random errors became** (more or less) **neglible**
- tighter **focus on** so-called **unknown systematic errors**
  e.g. ambient temperature, degradation, instrument error, …

**The metrological answer was given** (as late as) **1993**
**by publishing the GUM !**

See www.bipm.org/en/publications/guides/

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## The Guide to the Expression of Uncertainty in Measurement

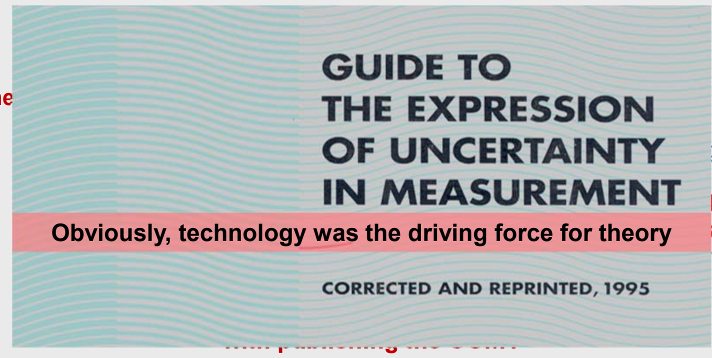
The Data-Evaluation Problem of the 60th/70th – A Brief Review

**State-of-the Art of uncertainty evaluation up to the mid-80th:**

A
B

**The**

C
D




**Obviously, technology was the driving force for theory**

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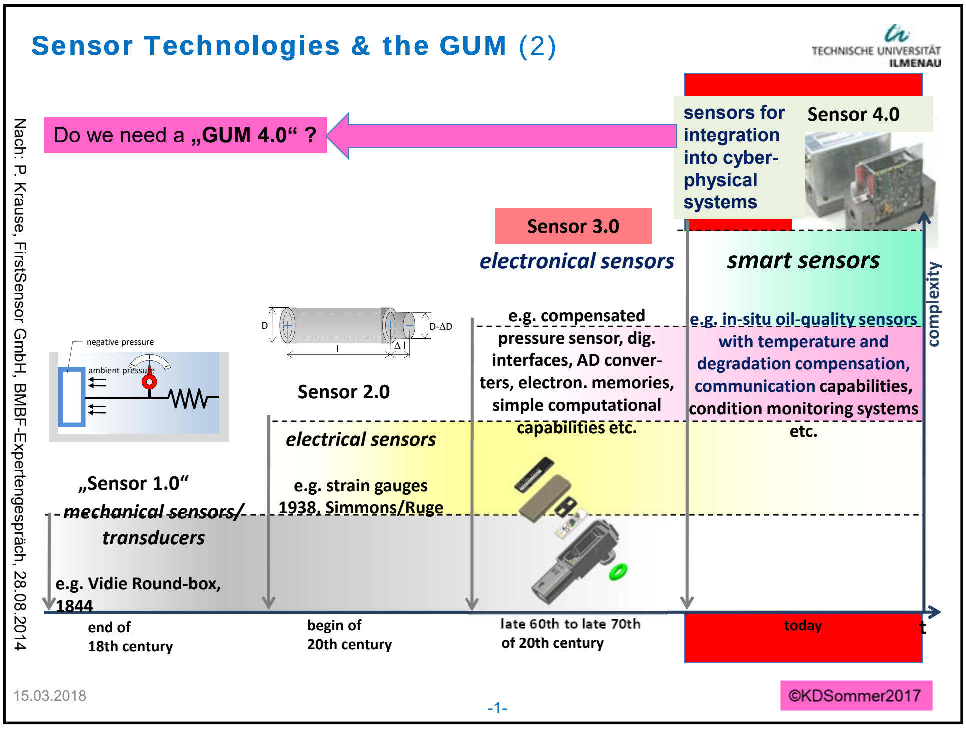
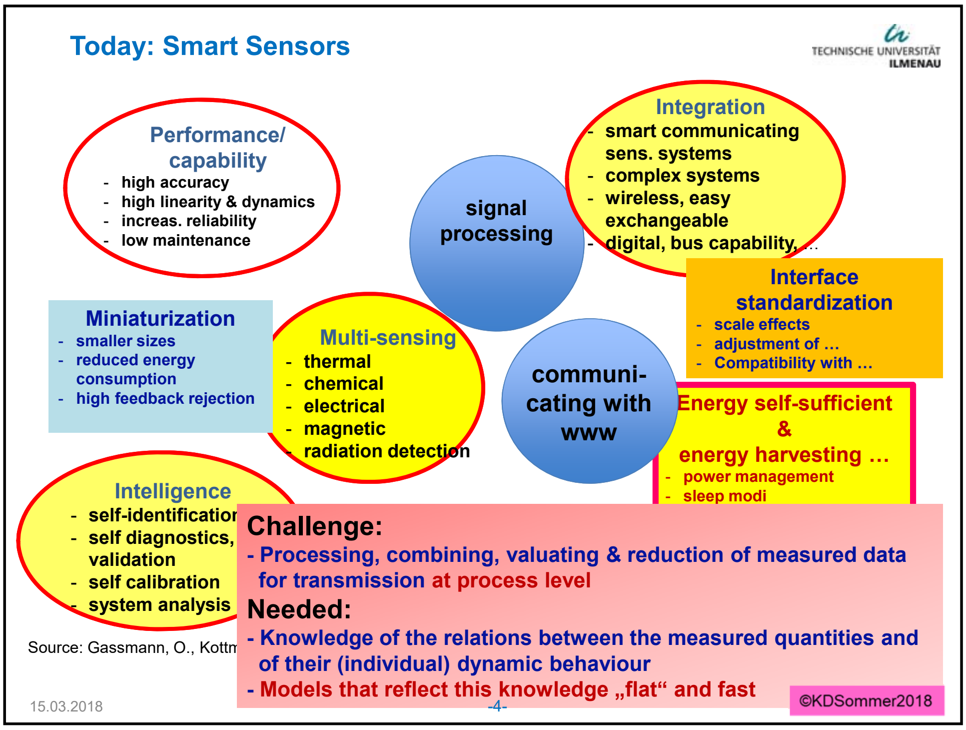
# Emerging Calibration & Traceability Challenges



# Emerging Calibration & Traceability Challenges

## Challenge: Condition Monitoring (1)

Example: Characteristic Damage Function

(LDA - linear discriminant analyzis)

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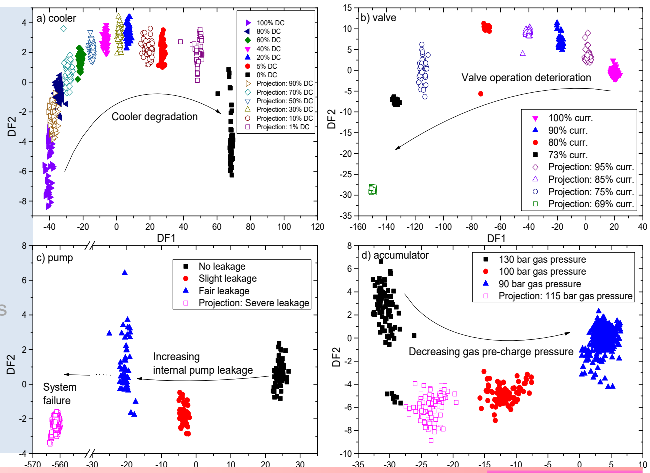
- Damage process is represented in 2-D LDA-space
- DF1 enables the quantification of the damage grade
- Evaluation of the statistical models by projecting of intermediate steps successful

→ **Calibration of the measurement/determination of the damage state !**




**Challenge:**



- **Nobody wants to know the detailed inormation avail. or can process it mentally. The essential, realy relevant part is needed, only!**
- **Big amounts of data and information resp. can‘t be transferred at process level!**

## Challenge: Condition Monitoring (2)

Satisfying Customers Demand – Trend Beyond Classical Measurands?

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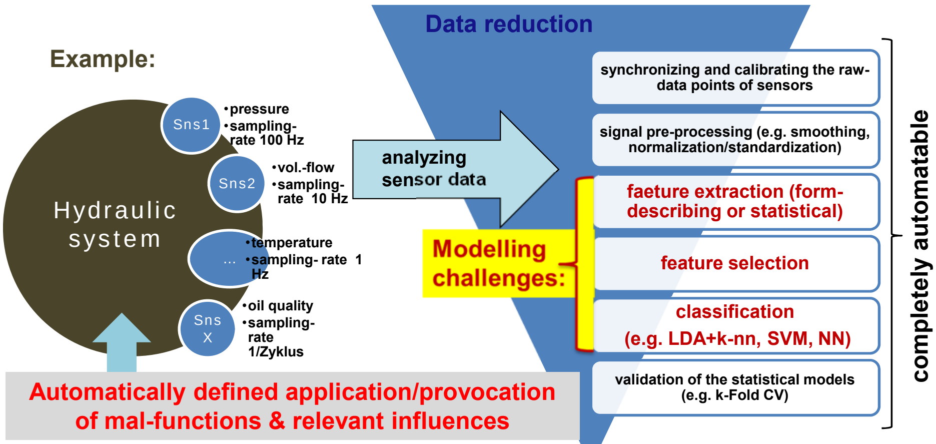


**Condition monitoring – Determination of relevant system states**
instead of individual measurands, e.g.

- *Maintance needed*
- *System needs your attention – or don‘t touch the system*



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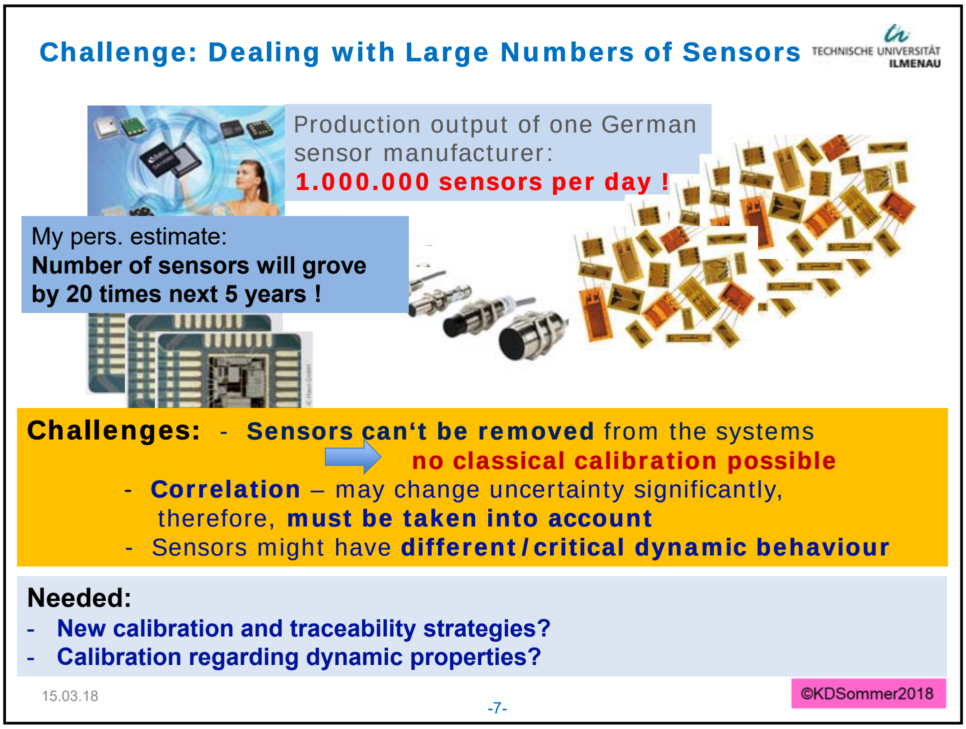
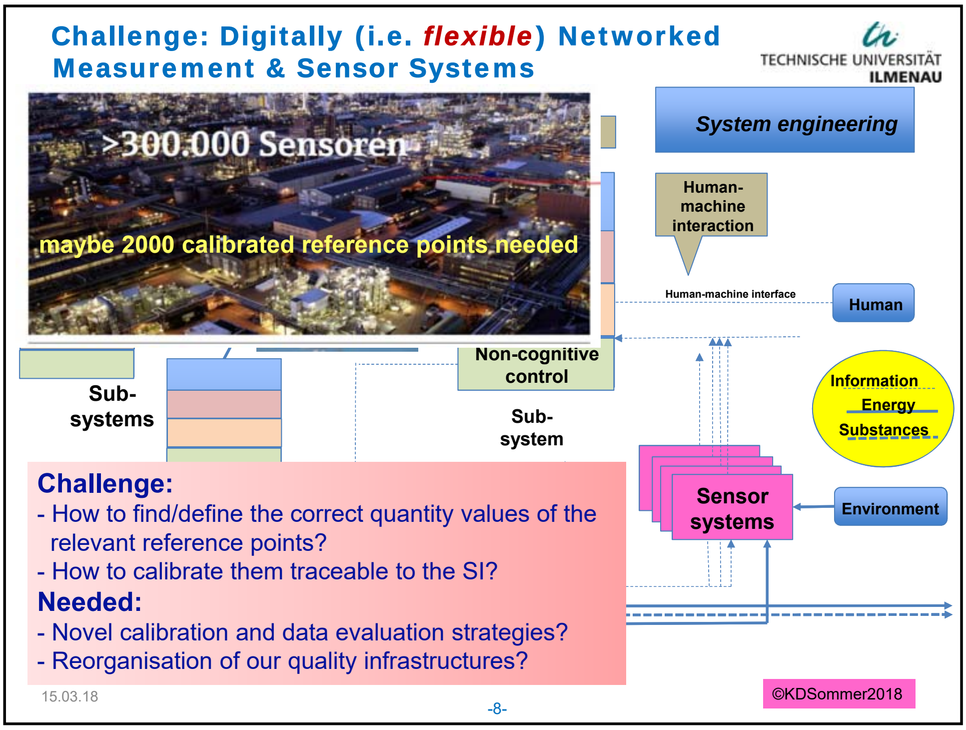
# Emerging Calibration & Traceability Challenges



# Emerging Calibration & Traceability Challenges

## A New Opportunity: The New SI

Direct Traceability to the *Defining Constants*

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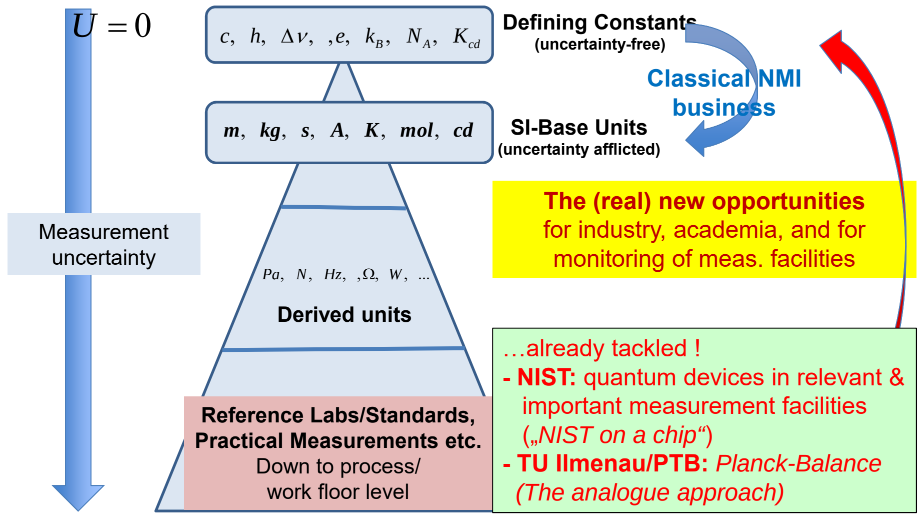


**The (real) new opportunities** for industry, academia, and for monitoring of meas. facilities

…already tackled !
- **NIST:** quantum devices in relevant & important measurement facilities („*NIST on a chip*")
- **TU Ilmenau/PTB:** *Planck-Balance (The analogue approach)*

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## Example: Direct Traceability to the *Defining Constants*

Analogue Approach: Planck Balance (TU Ilmenau/PTB)

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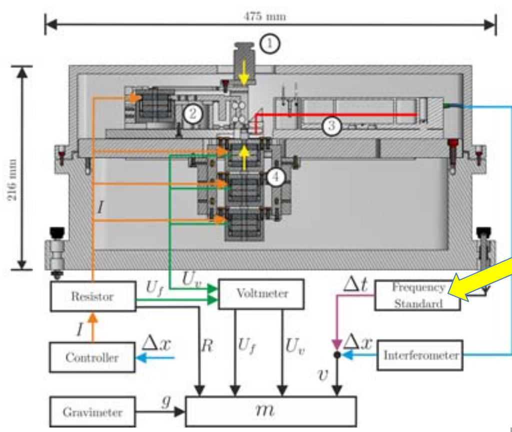
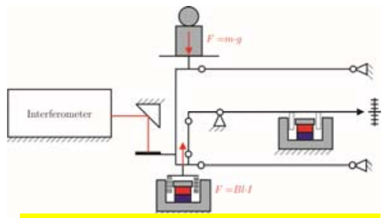
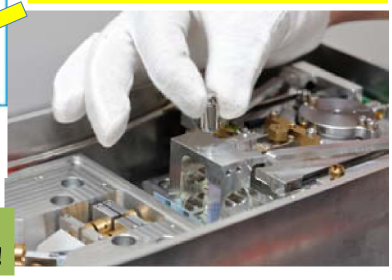



e.g. traceability to the „s"



**Highest accuracy of** the mechanical, the electrical and the dynamical **model required !**

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# Emerging Calibration & Traceability Challenges

## Novel Approaches to Ensure Traceability
Approaches at **Lower Hierarchy-Levels**

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Selected approaches:

1 **Utilizing virtual standards - *digital twins* -**
e.g. virtual coordinate measuring machines


2 **Self-X strategies,** incl. self-provocation/defined change of influence quantities, comparison with colla-borating sensors of the system as well as …

3 **Artificial-intelligence solutions, e.g. machine learning -** fast checking a large number of (mostly data-driven) model combinations
(preferred by German sensor and instrumentation manufacturers)
**All these solutions are to be combined with**
- Classically calibrated references
- Built-in or system-inherent references

or to be traceable directly to the *Defining Constants*
Additionally:
- Application of *big-data* methodologies
- Reference to plausible environmental values, e.g. *smart-phone sensors*

4 …

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## Utilizing *Digital Twins*
Example: Holistic Dimensional Measurements

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**Example:** Quality check of a whole vehicle body, regarding
- Form/Shape
- Dimensions
- Surface quality
- Colour
- Defects
- …

**Ensuring measurement correctness:**
- utilizing a **virtual standard / digital twin** of the complete car body
- Model includes the thermal behaviour, material properties, mechanical stress responses and uses empirical uncertainty values …

**Virtual standards are models !**

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# Emerging Calibration & Traceability Challenges

## Conclusion: There Seems to be a Clear Need to Extend the GUM

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Based on its proven *Bayesian* way, the GUM should to be extended to enable it to recognize i4.0 technologies in measurement:

- Generally, the GUM should be extended to be capable to **deal with (flexible) networked measurement systems**
- **Modelling** (parametric, data-driven, „flat & fast", including data/information reduction and classification) will become a **key competence of uncertainty evaluation**
- **Quantifying Traceability reliability** in case of **virtual standards –** digital twins?
- Uncertainty propagation through **machine learning** solutions?
- Due to the future dominating role of (flexible) data processing, reduction and transmission, use of **information measures & sensor data fusion** come in focus again!
- **Dynamic effects** will play an increasing role, and … (much more)

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