

How reducing measurement uncertainty impacts economic loss?

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Abstract

The Measurement uncertainty refers to the potential for inaccuracy in measurements, which can affect production processes, product quality, regulatory compliance, and even research. When measurement uncertainty is not controlled, it leads to increased costs, inefficiency, and waste, ultimately resulting in economic losses. Reducing measurement uncertainty can significantly improve decision-making, optimize resources, and increase profitability. In manufacturing, measurement uncertainty in critical dimensions or properties of products can lead to defects, rework, and waste.

Think about a company that makes precision parts, like engine parts, where a crucial dimension has a tolerance of ± 0.01 mm. Measurement uncertainty: ± 0.005 mm Tolerance: ± 0.01 mm Parts may be fabricated outside of the permissible range if the measurement error is not taken into consideration. For instance: Parts that are rejected due to dimensions that are outside the tolerance range may incur additional material costs and labor to rework the components. - In contrast, components that are within the uncertainty range but nonetheless fall outside of acceptable requirements might be employed, which could result in product failure in end-use applications and necessitate costly damage control and recalls. For a production run of 10,000 components, the total cost of rejects would be as follows if the measurement uncertainty causes a 5% component rejection rate and the cost of producing each rejected component is \$50: 10,000 components times a 5% rejection rate times 50 USD equals 25,000 USD.

The rejection rate could be decreased and thousands of dollars in manufacturing costs could be saved by lowering uncertainty through improved calibration and measuring methods. In industries like power generation or manufacturing, inaccurate measurements of energy consumption or fuel efficiency can lead to wasted resources and increased operational costs. By reducing uncertainty in energy measurement, companies can optimize energy usage, leading to cost savings. For example, a power plant that burns 1,000,000 tons of coal annually could save \$1 million (\$1 million) in fuel costs annually by reducing the measurement uncertainty in calorific value by improving calibration and measurement techniques.

Uncertainty Impacts in Different Areas

Trade & Commerce

In trade and commerce uncertainty of measurements can affects significantly. For example. Certification of NIST SRMs for sulfur in fossil fuels uses a definitive method, developed at NIST, that virtually eliminates bias and significantly reduces the measurement uncertainty which translates to improved production efficiency (Hratch G. Semerjian, 2009). Moreover, inaccurate and fraudulent of measurements devices can led to economic distortion, for example in Brazil on fuel dispensers found that if 1% of devices were fraudulent (i.e. intentionally skewed to create a systematic error), the range of economic distortion increased dramatically—from an uncertainty of about US\$104 million to over US\$350 million in market value. In that scenario, the estimated losses borne by buyers rose from approximately US\$55 million to over US\$303 million, illustrating how even small proportions of measurement error can lead to enormous economic (Bruno A. Rodrigues Filho). In 2014, the European Union temporarily banned Indian mangoes due to pesticide residue measurement disputes, costing India \$15 million in lost exports and damaging trade relations (APMP).

Health

Accurate measurements underpin not only industrial processes but also critical areas like health, environmental monitoring, and public safety. For instance, precise measurement in healthcare (e.g., dosing in pharmaceuticals) or environmental regulation (e.g., pollutant levels) is vital for protecting lives and reducing long-term social costs. Conversely, uncertainties can lead to market asymmetries where consumers bear disproportionate losses, thereby undermining trust in both products and regulatory frameworks. For example, Medication Errors: Dosage inaccuracies contribute to \$42 billion in annual U.S. healthcare costs and 7,000–9,000 deaths. Accuracy of medical devices affect the outcomes significantly, In low-income countries 30% of medical device failures stem from calibration errors, which cost \$1.8 billion annually (National Library of Medicine). Another study evaluating the impact of calibration errors, even a small systematic bias of 0.1 mg/dL in calcium measurements was estimated to increase follow-up healthcare costs by about US\$8–US\$31 per patient. If we assume that about 3.5 million patients per year undergo these tests in the U.S. and are affected by such a bias, then the total additional healthcare cost could range from US\$60 million ($3.5 \text{ million} \times \text{US\$8/pt}$) to nearly US\$199 million ($3.5 \text{ million} \times \text{US\$56/pt}$) per year. (Jon Shreve)

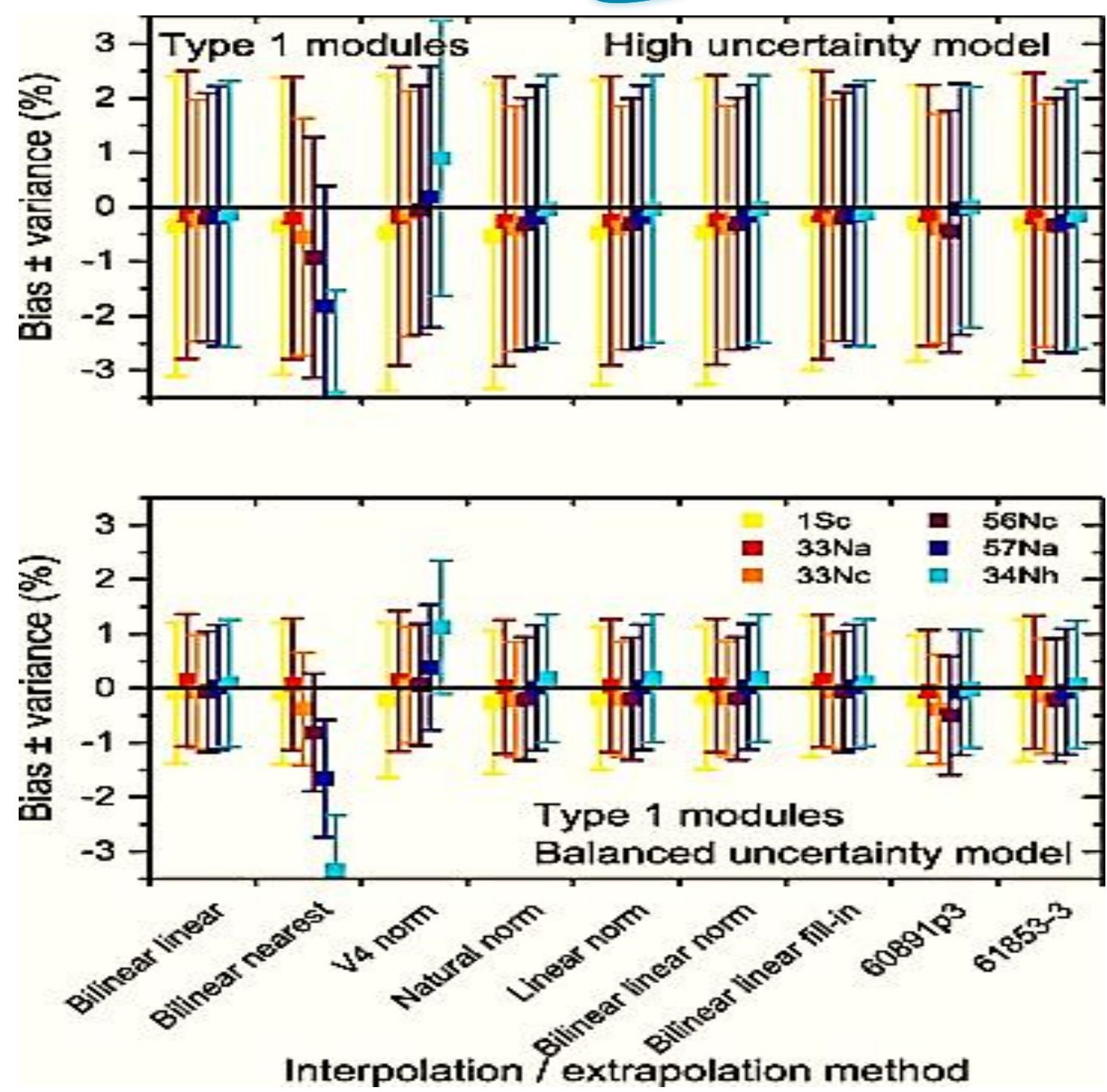
Uncertainty Impacts in Different Areas

Innovation

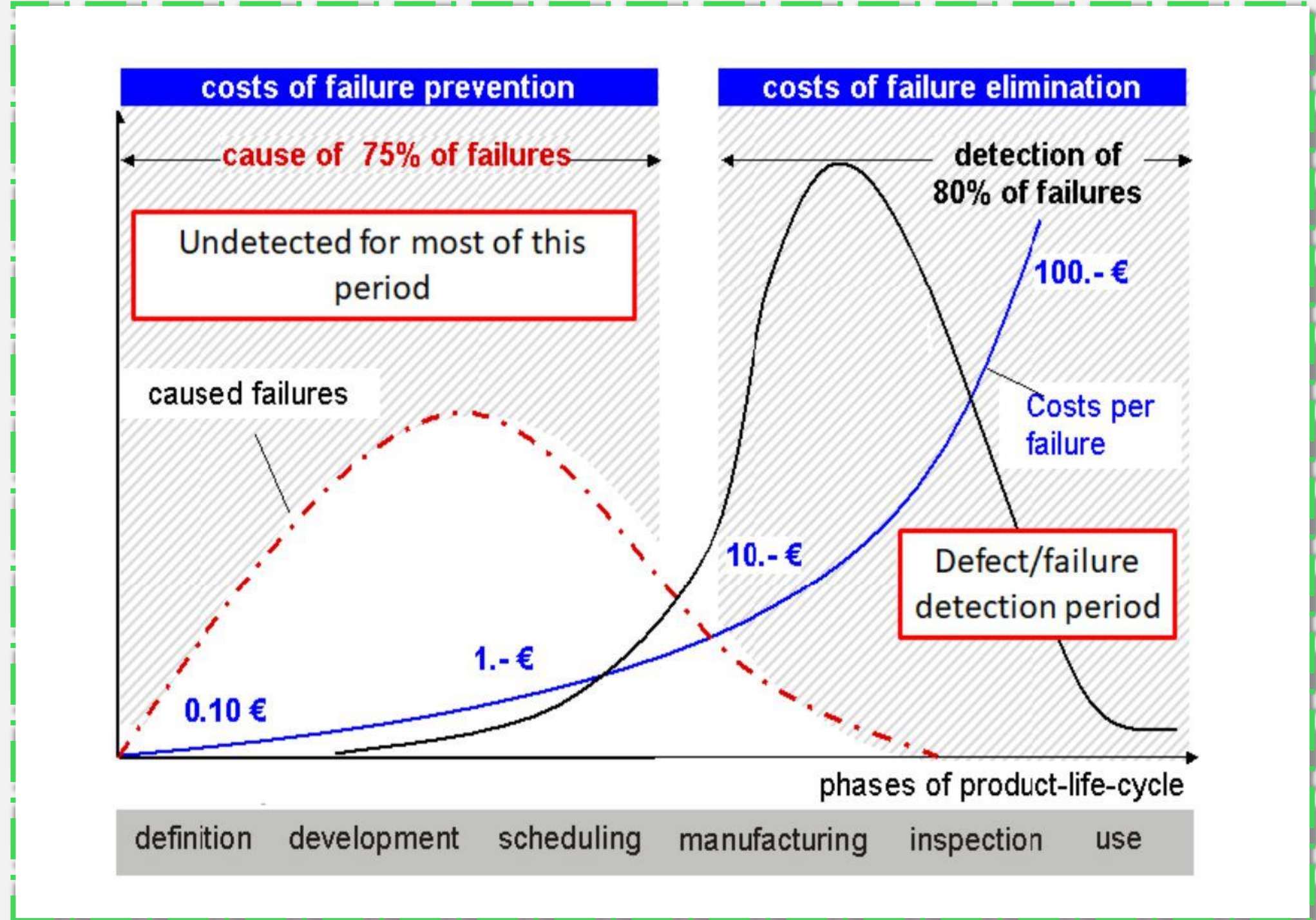
Beyond direct productivity gains, robust metrology infrastructures also foster innovation and consumer safety. In some sectors, benefit–cost ratios from improved measurement standards can range widely—from 4:1 in building technology to as high as 249:1 in information technology—with an average near 47:1. Such high ratios indicate that the economic benefits from reducing measurement uncertainties can vastly outweigh the costs of implementing and maintaining advanced metrology systems (Kristel Robertson).

Energy

Energy is a critical sector where every measurement is crucial in safety and delivering the service efficiently, Consider a state where annual electricity consumption is 100 terawatt-hours (TWh) and the average electricity price is US\$0.10 per kilowatt-hour. This amounts to annual electricity sales of about US\$10 billion. If the metrological uncertainty in the electricity meters is $\pm 1\%$, this introduces a potential error of ± 1 TWh. At US\$0.10 per kWh, a 1 TWh error translates to about US\$100 million per year.



Statistical analysis of the energy rating error for 1000 type 1 virtual modules for each of the interpolation methods with measurement uncertainty included.



An example of how early errors are frequently overlooked and are typically discovered too late in the final processes [5]

[1] Bruno Amado Rodrigues, Economic distortion as an indicator to measure the impact of legal metrology activities, 2023
[2] Jon Shreve, The Economic Measurement of Medical Errors, 2010
[3] Kristel Robertson, economics of metrology, 2015
[4] Hratch G. Semerjian, Economic Impact of Chemical Metrology Programs, 2009
[5] Kunzmann, H., Pfeifer, T., Schmitt, R., Schwenke, H. and Weckenmann, A., 2005. Productive metrology-adding value to manufacture. CIRP annals, 54(2)
[6] James C. Blakesley et al., Accuracy, cost and sensitivity analysis of PV energy rating, Solar Energy, Volume 203, 2020, Pages 91-100

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