
Preface

Every time anyone takes a measurement, the only certainty is that the measurement is not exact. This is even true if you are a highly skilled and qualified metrologist; all measurements have some amount of uncertainty associated with them. For example, if we state that the temperature in a room is 70 °F, we do not mean that the temperature is *exactly* 70 °F. We probably mean it is close to 70 °F. Also, we do not mean that the temperature *everywhere* in the room is 70 °F. There may be hot spots close to radiators or running electrical equipment and cold spots near air conditioning vents.

Even “accurate” measurements have some degree of uncertainty. Take, as an example, the problem of weighing yourself on a bathroom scale. You may step on the scale once, or 10 times, or 100, or 1000. Let us assume that every time you step on the scale you record almost exactly the same weight. You may come to the conclusion that since all of the measurements were very close, you know your weight “accurately.” But it is most likely that the bathroom scale has an error (for example, a zero offset) and you have very accurately got the wrong answer!

The concept of uncertainty is that there is always some doubt about a measurement. We can never remove all doubt, but we can aim to estimate and understand it. The theory and examples presented in this booklet aim to develop a quantifiable range within which the true value falls. This range, or uncertainty interval, cannot be determined exactly since we never know exactly how accurately any one measurement has been made. Consequently, when we quote uncertainty we always include a probability. This is the probability that the true quantity is within the quoted range.

So why is there an uncertainty in our measurements? Some uncertainty is due to the accuracy of the transducers we use to take measurements, and some is due to variability in the item being measured. In this booklet we will identify the most common sources of uncertainty. We will then see how these uncertainties can be combined so that we can identify the uncertainty in an actual measurement. Once we know the uncertainties in individual measurements, we will combine their uncertainties so that we can estimate the uncertainty associated with more complex engineering measurements.

The most recent theories of measurement uncertainty were first published by ISO¹/BIPM² in 1992 in the “Guide to Uncertainty in Measurement,” often referred to as the GUM. While the GUM is not a standard in the strict sense, it is the basis on which standards dealing with metrological subjects are drawn. Prior to the GUM, uncertainty analysis of measurements was an uncertain exercise requiring much good (or bad!) engineering judgment. Uncertainties and errors were categorized as either B-Bias or P-Precision errors, and the mathematical analysis often gave final estimates of uncertainty that were unrealistic and not useful. Since publication of the GUM, measurement uncertainties are grouped into two different categories: Type A and Type B. Type A uncertainties are those which are evaluated by statistical methods, and Type B are those which are evaluated by any other means. The new methods presented in the GUM give much more realistic and useful estimates of the uncertainty associated with individual measurements and calculated quantities.

Companies wishing to demonstrate their quality management system often get ISO 9001 certification. ISO 9001 is one of the most widely used management tools in the world today, and the most recent certification, ISO 9001:2008, has been in effect since November 2010. The next version of the standard is anticipated in 2015. Companies seeking ISO 9001 certification are required (among other things) to document transducer calibration and traceability. While ISO 9001 does *not* require all measurement systems to be calibrated, it does require calibration of those that contribute significantly to the control or verification of the quality of the product. One way companies can show whether a particular measurement system contributes significantly or not to their process is to perform an uncertainty analysis using the techniques outlined in the GUM and in this monograph.

This monograph explains the theory and methods in the GUM in a way that is approachable to the practicing engineer. We then present an extended case study. The case study presents many practical aspects of an uncertainty analysis in a form that can act as a template for the study of a different system. The case study also discusses different types of uncertainty budgets that can be developed using the results from an uncertainty analysis. Uncertainty budgets are a popular way of identifying where cost savings in a process can be made, or identifying whether a proposed change is cost-effective or not.

By necessity this monograph uses some statistics and calculus. We assume that most readers have seen this level of mathematics previously, but have probably forgotten the details! Therefore, we aim to explain the mathematics as non-mathematically as possible. The focus of this monograph is the understanding and application of uncertainty, and while we identify the essential mathematics we did not feel this booklet is the right place for detailed mathematics and statistics theory. If you want a book on mathematics or statistics, there are many excellent texts available on the market.

We hope that you find this book useful as you develop uncertainty analyses and budgets for your own systems.

¹ International Organization for Standardization.

² International Bureau of Weights and Measures.

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An Introduction for Engineers and Students

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