

Industrial methodology for uncertainty in quality and process improvement

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1 Abstract

This paper considers the interrelationship between measurement uncertainty and process variation in production. It indicates how current government- and industry-supported work in the UK are combining to assist in improving the communication between industrial engineers and metrologists. Other related issues are discussed.

2 Introduction

The field of metrology has the valuable asset of providing a means of evaluating and reporting uncertainty that is supported by a widely respected international guidance document, the Guide to the Expression of Uncertainty in Measurement (GUM) [2]. It is also supported by national implementations of the GUM, such as that [6] by the United Kingdom Accreditation Service. The GUM is accepted and used by very many organisations worldwide. There are many potential benefits of adapting the GUM to become a common means of evaluating and reporting uncertainty in other fields within industry in which uncertainty is encountered. These include (a) optimised processes, (b) a core subject within technical and commercial training, (c) ease of communication, (d) commonality of documentation and (e) improved mobility of skilled personnel.

Relevant work supported by the National Measurement System Policy Unit (NMSPU) of the UK Department of Trade and Industry (DTI) is the NMS *Software Support for Metrology* (SSfM) programme [5]. One project within this programme is *Uncertainties and statistical modelling*, within which attention is being paid to the above issue, under the title *Industrial methodology for uncertainty in quality and process improvement*.

The wide range of prediction and measurement activities within industry, each with its own means of expression, makes the prospect of complete unification at least daunting if not impossible. The approach taken in the current SSfM work is to start by creating a unifying link between two important, closely related activities. These are Statistical Process Control (SPC), used to monitor process output through time, and measurement uncertainty.

3 Communication among skill groups

The improved communication so facilitated between manufacturing engineers and metrologists will help to direct process improvement activities to reduce the variation of a product, both in terms of deviation from its target value and the spread of values, and to eliminate non-conformance.

Advances in information technology continually allow the flow of information to increase in speed and volume between the skill groups contributing to a project. Within industry, much attention is paid to removing obstacles to that flow, an example being the use of common file formats. In contrast, the means of expressing measurement uncertainty varies considerably between skill groups, greatly inhibiting the communication process.

Metrologists may handle uncertainty with dexterity within their own activity, manufacturing engineers may do so in their domain, materials scientists similarly in theirs, etc. Until uncertainty is perceived, evaluated and expressed in a consistent manner across the relevant disciplines, however, much of the value of this activity will remain relatively isolated, with its full potential for commercial exploitation beyond reach.

An intention of the SSfM work in the area is to assist in overcoming this communication and language barrier.

4 Example: measurement uncertainty meets process variation

Statistical process control is in widespread use as a quality management tool. Within SPC in a manufacturing environment there are interactions between uncertainties that are traditionally handled by two different skill groups. Measurement uncertainty is the domain of the metrologist and process variation the realm of the manufacturing engineer. The interface between the two must allow essential information to be communicated.

A simple example of measurement uncertainty meeting process variation can be illustrated by a stack of ten nominally identical discs (e.g., coins). The measured height of the stack and the value predicted from thickness measurements of sample discs would not be expected to yield identical results. There are a number of sources of uncertainty that would contribute to the difference. These include the measurement uncertainty of the stack height, the measurement uncertainty of the thickness of a disc, the disc-to-disc variation in thickness, and the variation in how the discs stack together, e.g., in the thickness of a layer of glue.

There is a distinction between two types of uncertainty here. The stack is measured and some individual discs are measured. There will be measurement uncertainty associated with *these* measurements. The remaining two items are different, being the result of process variation. There are two types of process, that associated with producing the discs (disc-to-disc variation within the disc-production process) and that with providing the glue layers (layer-to-layer variation in the glue deposition and curing processes). Because, typically, each disc in the stack is not itself measured, with a similar statement for each layer of glue, the information about the corresponding uncertainties is available only from statistical analyses of the measurements of the sample discs and of measurements of representative layers of glue. The results of these statistical analyses would provide information about the variation of the relevant processes.

There is thus a very important distinction to be made between measurement uncertainty (in the above example related to sample disc and stack height) and process variation (disc-to-disc variation and glue-layer variations as a consequence of the respective processes). The classification and understanding of these effects will undoubtedly be beneficial to all stages of the manufacturing process from design to inspection. A detailed illustrative example is available of the various uncertainty sources that are present in another (superficially) simple measurement [3, p22].

The quantification of the relative influence of measurement uncertainty to that of process variation is key to handling SPC and product conformance. If measurement uncertainty were negligibly small compared with process variation and specification limit ranges, process control decisions would be insensitive to the methods by which the measurement uncertainty were evaluated and considered alongside process variation. If, however, measurement uncertainty were not negligible in this sense, it would influence SPC, introducing difficulties regarding the decisions concerning conformance. It would not be possible to assert conformance or non-conformance in the same way: there would be additional doubt introduced by the effects of measurement uncertainty. As processes become controlled more tightly, measurement uncertainty will become relatively more important. It may well be necessary in some cases to invest in more accurate measurement systems to alleviate the difficulty.

It is evident that the quantification of the relative effects of measurement uncertainty and process variation is essential to making sound decisions.

The “consistency loop”, shown in Figure 1, is a simple graphical representation of a comparison that could be made between measured values and the sources of uncertainty that should be considered in determining whether the overall uncertainty of the comparison explains the difference. It is applied here to the disc-stacking problem. Its use in the analysis of complex processes can help identify which sources of uncertainty are in the loop and which are not. An essential aspect of a consistency loop is that different skill groups are required to contribute information to allow it to be created. Establishing an awareness of this need will be an important driver to obtaining improved communication among skill groups.

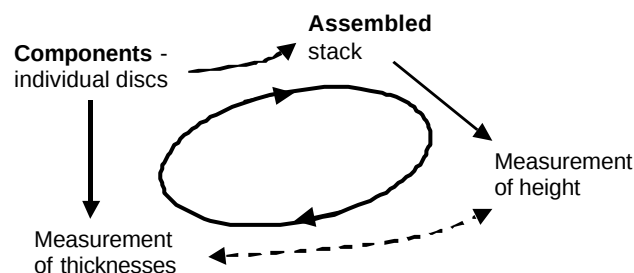


Figure 1. Example of a consistency loop applied to the disc-stacking problem.

As indicated, the requirement to demonstrate that components conform to specification has generated the need for methods to assimilate measurement uncertainty into the spread of a manufacturing process. There are many

different procedures for carrying out Gauge R&R (Repeatability and Reproducibility) studies in SPC. There are several respected documents in this field [1, 7].

A single method (or at most a class of methods or set of tools) is required, that is simple and accessible to a wide audience, yet based on sound theory. A progressive gradation in complexity of consistent tools would assist accessibility at one extreme, and make possible the solution of complex problems at the other.

5 Objectives and benefits of the current Software Support for Metrology programme

An objective in the medium term of the current SSfM programme (April 2001–March 2004) is to express SPC in terms of the terminology and concepts of the GUM. In addition, an industrially orientated glossary of terms used in metrology will be produced to help acclimatise engineers to measurement uncertainty and to assist in discussions between manufacturing engineers and metrologists. A guide will be produced on how to assimilate measurement uncertainty into the spread of a manufacturing process. Training-course material based on the guide and the glossary will be developed, the target audience being manufacturing engineers and metrologists, with the emphasis on the intersection of their fields of interest.

A number of benefits from the activity are expected. There will be improved communication between manufacturing engineers and metrologists, helping to overcome the different perceptions of the interface between manufacturing and metrology. In turn, opportunities for process improvement will be identified and exploited more naturally than they would otherwise have been. Those personnel who gain skills in measurement uncertainty will increase considerably their mobility: the generic skills gained in handling uncertainty in one job will be more readily transferable.

6 Long-term aim and related issues

A long-term aim is to adapt the GUM to become a common means of expression of uncertainty within industry. One possible mechanism for this will be through the GUM maintenance process. The Joint Committee for Guides in Metrology (JCGM) [4], a body of which one of the authors of this paper is a member, is revising the GUM. The revision is concerned with amplifying and emphasising key aspects of the GUM in order to make that document more readily usable and more widely applicable. It is to be achieved through the preparation of supplemental guides. Consideration will be given to the possibility of devoting a supplemental guide to the area addressed by this paper.

It is anticipated that industrial measurement uncertainty will become recognised as a common core subject to be studied by technical students and will count as a module towards a professional qualification. There would be benefit if it became a common language for trade and industry, through industrial need from one direction and the influence of standards from the other.

The authors believe that such considerations would assist the formulation of subsequent SSfM programmes, which, if accepted by the DTI, would help to accelerate the progress of UK engineers in this field. Other, closely related activity such as engineering tests, Analytical Design Techniques (ADT) and generic aspects of commercial models could well be covered in these programmes. Linking these methods will allow a consistent methodology to be created to cover a wide range of industrial activities (Figure 2).

Although further activity is anticipated in the future, work is already taking place in the current SSfM programme on producing guidance on continuous modelling, concerning the finite-element and finite-difference software that is frequently used by industry as analytical design tools. Case studies will be provided on the manner in which uncertainties influence the results from such software. Three types of uncertainty arise, viz., model uncertainty (a measure of the closeness of the model to reality), solution uncertainty (the uncertainty contribution arising from the use of discretisations—such as finite elements—to solve a continuous problem), and parameter uncertainty (as a consequence of the inexactness of the materials constants and the geometrical dimensions of the problem solved). Because there is doubt about the quality and appropriateness of some of the available software that implements the solution procedures, a further important element within the current programme is the testing of that software to identify the “software uncertainties”.

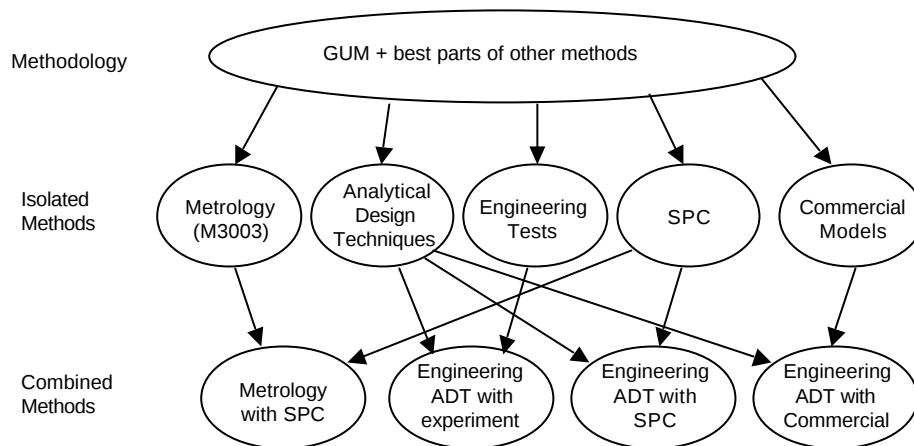


Figure 2. Overview of proposed methodology.

Work on conformance in the presence of uncertainty will also feature in future SS/M work. Currently, a small start is being made in reviewing the standards that are emerging in several disparate disciplines ranging from geometrical product specification to environmental regulations

7 Conclusions

This paper has identified the problem of communicating uncertainty between skill groups in industry, and indicated some of the effects of that problem. It has suggested an approach that adapts the GUM to become a consistent methodology to express uncertainty in a wide range of industrial activities. Not only will this approach create a common language for uncertainty, but also it will establish a route to enable working-level procedures to exploit more rapidly future developments in international standards for measurement and uncertainties.

Technical advances in one field of uncertainties may be applicable to others, yet a lack of discussion between skill groups reduces the opportunity for such cross-fertilisation. The potential for work carried out by a National Measurement Institute to influence the activities in the industries it supports is severely limited if neither party can immediately understand the terms used by the other. A common language has the potential to enhance the prospects for wider discussion and so stimulate further technical advances.

The GUM itself states in its scope "... the principles of this *Guide* are intended to be applicable to a broad spectrum of measurements, including those required for ... maintaining quality control and quality assurance in production ...". Thus, the intention of the work described is wholly consistent with the aims of the GUM.

8 References

1. Automotive Industry Action Group. Measurement Systems Analysis Reference Manual. Second Edition, 1995.
2. BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, and OIML. Guide to the Expression of Uncertainty in Measurement, Second Edition, 1995. ISBN 92-67-10188-9.
3. M. G. Cox, M. P. Dainton, and P. M. Harris. Software Support for Metrology Best Practice Guide No. 6: *Uncertainty and statistical modelling*. National Physical Laboratory, Teddington, UK, 2001.
4. Joint Committee for Guides in Metrology. www.bipm.fr/enus/2_Committees/JCGM.
5. NMS Software Support for Metrology programme. www.npl.co.uk/ssfm.
6. UKAS. The expression of uncertainty and confidence in measurement. M 3003, United Kingdom Accreditation Service, 1997.
7. D. J. Wheeler. and R. W. Lyday. Evaluating the Measurement Process. Addison Wesley, 1990.