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Pathways to digitalisation at the Measurement Standards Laboratory of New Zealand

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***Abstract* – Several strategic initiatives undertaken by the Measurement Standards Laboratory of New Zealand in response to the digital transformation of metrology are discussed. While the laboratory does not currently perceive an external demand for the digital delivery of its metrological services, it recognises that change will be required as global support for digital services becomes the norm. To support the longer-term vision of semantic representation of metrological data, a shift will be required from procedural, process-based knowledge capture towards abstract scientific forms. MSL has several initiatives in place to prepare for and facilitate this transition.**

I INTRODUCTION

The international metrology community recently announced its intention to digitally transform national and international measurement quality infrastructures (QIs) [1]. This will have far-reaching effects, as these QIs underpin metrologically traceable measurement services worldwide. All modern economies stand to benefit from increased efficiencies and new ways of using measurement data enabled by digital technologies. Achieving a successful outcome from digital transformation will require exemplary leadership and coordination at the highest levels, together with wholehearted commitment and engagement in digitalisation activities throughout the metrology community. To support this, the International Committee for Weights and Measures (CIPM) established a Forum on Metrology and Digitalization (Forum-MD) in 2019, to advise on the broader implications of global digital transformation in metrology [2, 3].

There are both international and national perspectives to this digital transformation in metrology. Internationally, a shared digital infrastructure is needed to support the exchange and unambiguous interpretation of measurement data. To enable increasingly autonomous machine use, this infrastructure must address and resolve ambiguities and inconsistencies that exist in current normative standards. Nationally, there is a need to adapt to a diversity in the rules and regulations imposed by local authoritative bodies. While each economy maintains sovereignty over its affairs, digitalisation will have to negotiate a greater degree of harmonisation across jurisdictions.

This conference paper describes the challenges and opportunities presented by digital transformation in metrology from the perspective of a small and geographically isolated economy—New Zealand. New Zealand is a member the international Metre Convention, which establishes a world-wide system of measurement units.[1] The country's national metrology institute (NMI)—the Measurement Standards Laboratory of New Zealand (MSL)—plays a key role in ensuring that the nation's measurement system is internationally recognised.

By act of parliament, the Chief Metrologist at MSL is the verifying authority of the country's measurement standards [4, 5]. The laboratory is signatory to the CIPM Mutual Recognition Arrangement (MRA) [6], which provides a framework for NMIs to demonstrate the performance of their measurement capabilities, thereby supporting the global dissemination of measurement services. MSL's services are also assessed against the international quality standard ISO/IEC 17025 for calibration and testing laboratories [7]. The assessment is organised by New Zealand's accreditation body, International Accreditation New Zealand (IANZ), which operates in accordance with internationally recognised standards and is a signatory to the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Arrangement. The ILAC MRA ensures that IANZ accreditations are recognised by other ILAC MRA signatories and complements the CIPM MRA in supporting the international acceptance of measurement and calibration results. ILAC is one of nine signatories to a joint statement of intent with the CIPM, which seeks to involve stakeholders in international scientific and quality infrastructures in the on-going digital transformation in metrology.

In 2019, MSL allocated a small resource—about one half of a full-time equivalent (FTE)—to explore emerging metrology projects in digitalisation. Among the international developments that drew attention were two European-funded projects launched in 2018: SmartCom [9], and Metrology for the Factory of the Future [10]. Also, a few years earlier, an eloquent vision and strategy for dig-

[1]The Metre Convention (Convention du Mètre), also known as the Treaty of the Metre, is an international treaty signed in Paris on 20 May 1875. The treaty set up an institute for the purpose of coordinating international metrology and for coordinating the development of the metric system. In 1960, the system of units it had established was overhauled and relaunched as the "International System of Units" (SI). New Zealand became a full member of the Metre Convention in 1991.

ital transformation in metrology had been articulated in the United States by Kuster [11, 12]. MSL's strategic plan states that the laboratory will . . . *engage with international colleagues to share our expertise, as pre-normative standardisation takes shape, and [. . .] assess new technologies, as they emerge, for relevance to New Zealand*. So, it was appropriate to investigate these new digitalisation initiatives. Since 2019, the resource allocated to this area has grown to approximately 1 FTE.

MSL is not a large NMI by international standards, employing around 30 scientific and technical staff across a range of disciplines. Its expertise is world class, as reflected by membership in four of the CIPM Consultative Committees: those for mass (CCM), temperature (CCT), electricity and magnetism (CCEM), and photometry and radiometry (CCPR). MSL has approximately 180 Calibration and Measurement Capabilities (CMCs) published in the Key Comparison Database maintained by the International Bureau of Weights and Measures (BIPM). These CMCs span electricity and magnetism, photometry and radiometry, mass and related quantities, temperature and humidity, length, and time and frequency. Much of MSL's activity involves maintaining the metrological references and infrastructure that underpins these CMCs, as well as delivering measurement services to customers (approximately 260 measurement reports were issued to customers in 2024).

This paper discusses MSL's approach to digitalisation and digital transformation from a local perspective. While MSL has also been active internationally, and is a member of the Forum-MD, those activities are outside the scope of this paper. The local environment for digitalisation has presented challenges quite unlike those being addressed through international collaborations and research focused on the scientific principles of metrology.

The structure of the remainder of the paper is as follows. The next section outlines the environment in which MSL operates and how this has influenced the laboratory's approach to digitalisation. Section III describes two initiatives intended to better align the laboratory with the future demands of digital transformation. Section IV briefly discusses our ongoing strategy.

II THE ENVIRONMENT AT MSL

The environment in which MSL operates is shaped by the regional metrology organisation, Asia Pacific Metrology Programme (APMP), the national accreditation body (IANZ), and the needs of its customer base. In 2021, the APMP responded to the CIPM's growing interest in digitalisation by setting up a focus group to coordinate regional activities—the DXFG [13]. However, no digital policy decisions have yet been made by the APMP, nor has ILAC—IANZ's coordinating body—indicated any response to digitalisation. MSL surveys its customers regularly and has monitored for indications of emerging demand for digital services. To date, no such signals have been observed, and recent discussions with IANZ have confirmed our impression that there is no significant local 'pull' toward digitalisation. Accordingly, there is no immediate pressure on MSL to change its practices and offer digital services externally.

All MSL staff use digital systems for aspects of their duties. The laboratory has access to a corporate digital infrastructure that provides enterprise services such as email, networking, file storage, and office software. Specialised software can also be used as required; however, there is a reliance on commercial spreadsheet software for data analysis and word processing software for reporting. While these tools are familiar and well-established, they are not well suited to the rigorous quality control required by ISO/IEC 17025. The burden of developing and maintaining spreadsheets, and verifying their content, is recognised as a challenge across most sections of MSL, yet many metrologists are reluctant to move away from familiar tools. Although more appropriate digital systems may exist for certain activities, the perceived benefits are outweighed by individual preferences and practical considerations. Accordingly, there is little impetus within MSL to change practices.

Historical events may explain the reluctance at MSL to adopt new digital technology. MSL is embedded within a much larger organisation, where corporate priorities take precedence over the specific needs of the laboratory. In particular, the need for an NMI to maintain tight control of its technical records for decades does not sit comfortably with the much faster pace of change in commercial corporate IT systems. In the last ten years, MSL has endured three major corporate digital transformations, unrelated to metrology, which have been disruptive to the NMI. Given the impact of these changes, it is easy to imagine that even paper-based technical records may seem more effective and enduring than digital technologies.

Digitalisation, and ultimately digital transformation, are about much more than better record-keeping. The goal of digitalisation is to capture and codify information and metrological processes in forms compatible with digital systems—that is, in logical representations with well-defined semantics. Once such representations are available, metrology business models can be reconsidered, leading to a full digital transformation.

In a companion paper to this conference [14], we draw attention to challenges to digitalisation that arise within the metrology workforce. Many metrologists appear to favour empirical, experience-based forms of knowledge representation over abstract forms. Indeed, we suspect that the predilection for spreadsheet use at MSL is a reflection of this tendency—a preference for imperative rather than declarative software tools. If so, this may hinder efforts to digitalise.

Imperative software development defines tasks step by step—an approach that aligns with procedure-based experimental work. In contrast, declarative programming focuses on outcomes. Digitalisation will produce representations in structured, formal terms that are amenable to automation. This is a declarative approach, which may feel unnatural to metrologists accustomed to hands-on and procedural thinking. Yet it is precisely this shift—from tacit procedural know-how to explicit, formalised representations—that digitalisation requires.

III MSL'S APPROACH TO DIGITALISATION

The digitalisation strategy at MSL aims to help metrologists transition their work practices toward the more abstract declarative programming paradigm. The focus is not on adopting new technology *per se*, but on introducing a shift in the way metrologists approach their science. Incremental change, rather than large and disruptive shifts, is proposed. While we regard widespread digitalisation as an inevitable consequence of global trends, we do not perceive a need for substantial change at MSL. Instead, we see an opportunity to better position the laboratory for informed decision-making when the requirements for digitalisation and alignment with new international digital infrastructures become clearer.

A. Calibration reports

One example of our softly-softly approach concerns the process of generating customer calibration reports. The preferred tool for this task at MSL is Microsoft Word™. The software is used in an imperative workflow, where the author has full control over the appearance and contents of the report. There are strict guidelines for report formatting, so careful checking is essential before issuing each report. To save time, metrologists often use a previous report as a template for a new one. While expedient, this can perpetuate errors unless they are detected by careful checking.

An alternative to what-you-see-is-what-you-get word processing, LaTeX-based tools separate the specification of a document's appearance from its structure and content.[2] This is a declarative approach to document production where authors describe the content and structure of a document but not its appearance.

Recent enhancements to the LaTeX core have added support for documents produced in the PDF/A-3 format [15], which is an international standard for long-term archiving and preservation of documents. PDF/A files are self-contained and can be accurately reproduced regardless of the software or hardware used in the future [16].

A LaTeX class specifying the appearance of MSL calibration reports has been developed.[3] The class is declared at the beginning of calibration report text files to configure the LaTeX system, allowing authors to use the prescribed environments and macro commands (see Fig. 1).

```
DocumentMetadata{
    pdfversion=1.7,
    pdfstandard=A-3b,
}
\documentclass[CIPM]{MSLCalCert}

 \reportDate{2018-02-19}

 \reportNumber{Electrical/2018/Sxxx}
 \fileRef{J01xxx}

 \title{A report on the calibration of an ???}

 \workerChecker{Blair Hall}[RF Standards]
 \workerChecker{Neil Swift}
 \chiefMetrologist{Annette Koo}
```

Fig. 1. This shows the first few lines in a calibration report file. `\documentclass` *declares the MSL style,* `MSLCalCert`*, and selects a title-page option to include the CIPM MRA logo. Then various report details are declared, such as the report title and the staff involved in its preparation and validation.*

LaTeX report production is straightforward, and on efficiency grounds alone, there is an incentive to transition to LaTeX-based report generation. Because source files are plain text, content can be entered manually or automatically. Automation offers the opportunity to streamline workflows and reduce the risk of manual data-handling errors.

However, LaTeX also opens up digital enhancements at almost no extra cost to the metrologist. For example, PDF files support a feature called XMP (Extensible Metadata Platform), which allows XML metadata to be added to the file. This metadata can be accessed by document management systems for records management. In the MSL class, information processed by LaTeX—such as the title, date, report number, and other details—is written into the document's XMP metadata. The XMP format is extensible, allowing additional *ad hoc* information to be added. We plan to explore this capability further as a way of handling metadata required by ISO 17025.

Another advantage of the PDF/A-3 format is its ability to embed other digital files—such as calibration data—directly within the final report. These embedded files may use various formats, including spreadsheets or *ad hoc* formats specific to particular application software. We an-

[2]Maintained by the open-science community, these tools are freely available on various platforms and are renowned for their stability and long-term compatibility with legacy documents—an important feature for metrology. They are particularly well-suited for scientific reporting, with support for mathematical notation, units of measurement, and numerical data.

[3]A tutorial on the development of similar LaTeX classes is available online `https://apmp-dxfg.github.io/dxfg-pdfa-tut`.

ticipate that PDF reports containing embedded data will become a preferred pathway for MSL customers to transition from human-readable reports to machine-readable ones. Once again, the declarative approach greatly simplifies adoption of this enhancement by our metrologists: embedding an external file requires a single line in the LaTeX source.

B. *Measurement modelling*

A second MSL initiative encourages staff to develop appropriate scientific models of measuring procedures. Here again, the intention is to favour a declarative outlook over an imperative mindset. The connection between this initiative and digitalisation is indirect, as we shall explain.

When measurement results are reported outside MSL, the procedures followed must be documented and carefully controlled to comply with the requirements of ISO 17025. Such procedures can be, and often are, described as a sequence of actions—much like a recipe for the measurement in question. However, this procedural form of description is not easily reconciled with a scientific account of the same measurement.

ISO 17025 requires the measurement uncertainty associated with a result to be evaluated. This necessitates a formal scientific measurement model that accounts for all significant influence quantities—factors that cause a result to deviate from the measurand. A measurement model is inherently declarative, expressed in mathematical notation where the terms represent abstract physical quantities. Some staff prefer to elide the step of preparing such a model, opting instead to assert a relationship for evaluating the uncertainty. In some cases, this calculation is embedded in a spreadsheet, and it is claimed that "the spreadsheet *is* the model"!

To encourage better practice, MSL now offers tutorials on measurement modelling to staff who joined the laboratory in the last ten years. The syllabus introduces a straightforward and systematic modelling approach, previously published [17], that draws on familiar and fundamental ideas about quantities. This approach leads to a detailed description of how quantities in a measurement—some of which are undesirable influences—contribute to a result. Vague notions of *uncertainty* are avoided until a clear interpretation can be made in relation to residual measurement errors.

Models developed using the MSL approach are immediately compatible with special software for uncertainty evaluation [18]. In this approach, terms appearing in a model correspond directly to instances of an abstract data type called an uncertain number [19]. Mathematical expressions in the model can be replicated by identical source code calculations involving uncertain numbers. This design effectively separates the evaluation of measurement uncertainty into two tasks: first, the formulation of a model, and second, its evaluation. The software available at MSL takes care of evaluation. As a result, metrologists adopting this approach can spend more time on understanding their measurements and identifying sources of error, and less time on the mechanics of uncertainty propagation or the validation of associated software. The approach enables rigorous handling of complicated measurement set-ups and provides more accurate uncertainty evaluations than would otherwise be possible [20, 21, 22].

The self-discipline of formally modelling measurements leads to robust and streamlined data processing. When explicit models are included in measurement procedure documentation, they serve as independent tools for reasoning about the measurement process and the effects of influencing factors. The direct coupling between a model and uncertainty evaluation can be used to enhance the quality of measurement procedures and to support software validation. Furthermore, once a model is established, measurement uncertainty can be evaluated using different computational approaches, if desired, providing additional flexibility.

IV DISCUSSION

MSL's strategy is to encourage different ways of working with digital technology, some examples of which have been presented above. Our focus is on deep-seated issues rather than short-term technological trends. The strategy has several objectives: reducing exposure to disruptive external change, improving internal efficiency, and promoting approaches to metrological work that are suited to abstract, declarative expression. The transitions involved must proceed at a pace determined by metrologists themselves—they cannot be rushed.

Technologies, such as LaTeX tools, offer long-term stability. By facilitating the use of LaTeX, we are adopting a well-maintained and enduring digital system—one that can be relied upon for decades, if necessary. Producing LaTeX documents is a declarative way of working, helping metrologists to become accustomed to this way of thinking. At the same time, the PDF/A-3 format offers opportunities to move beyond conventional human-readable certificates. Its XMP metadata feature can be extended to hold metrological data, and its ability to encapsulate diverse file types is potentially very useful. In this way, we aim to be well-positioned to respond to external developments in the international quality infrastructure, as well as to meet customer expectations as demand grows for more direct delivery of digital data.

Our strategy recognises the fundamental role of semantics in digitalisation. Clear and consistent semantic definitions for metrological concepts will be essential—without these, semantic interoperability will not be achieved. Metrologists will increasingly need to engage with semantic digital technologies as the digital transformation of quality infrastructure takes shape. So, we are encouraging a shift from procedural, process-based knowledge capture toward abstract scientific representations—a shift reflected in our support for modelling.

More effort is needed in the area of semantics, which we plan to explore further. The terminology used within each metrology discipline must be systematically organised. Identifying and rigorously managing a domain vocabulary is a proven strategy in software development [23]. A well-defined domain language enhances collaboration by reducing jargon and minimising misunderstandings of discipline-specific terms. Adopting controlled vocabularies will improve the semantic alignment between technical documentation and quality-related processes such as software development and validation. We expect that careful attention to harmonised terminology will enhance the quality of work in the laboratory.

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