NMSA
AN INSTMC SPECIAL INTEREST GROUP

METROLOGY SKILLS FRAMEWORK
NMSA-1 - CORE STANDARD GUIDANCE

National Metrology Skills Alliance

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InstMC

NMSA Core Standard Guidance Notes

Foreword

These guidance notes have been written as a companion document to the main NMSA Skills framework standard. They provide further information regarding the details contained within the main standard and some of the underlying reasons why these topics have been included but written in a manner which is less 'technical'. The guidance notes will particularly support the users of the framework who may have less in-depth knowledge of metrology but provide reference information for all users.

The notes are not exhaustive and are intended to provide some insight into each section of the NMSA Core Standard. They are not written to provide comprehensive information as the application of metrology is broadly spread across countless industrial sectors and academic subjects but hopefully provide some additional insight. There are many reliable on-line sources of information on each topic, and these can be used should even greater insight be required.

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Introduction to Guidance Notes

The National Metrology Skills Alliance (NMSA) has defined a framework to fulfil a wide-ranging need for a structured approach to skills and qualifications for metrology practitioners and those who work with metrologists. The NMSA Core Standard (NMSA-1) has been deliberately written in a precise style that enables an easier transition to eventual formal recognition and publication as an ISO standard similar to ISO 9712:2012 that governs skills and qualifications for practitioners of Non-Destructive Testing (NDT).

It is recognised also that metrology touches a far wider spectrum of industrial and academic applications than NDT and that some of the language used may be unfamiliar to a wide range of non-metrologists that need to access and use this standard, and so these guidelines have been written in 'plain English' to give greater understanding to the NMSA-1 standard. These guidelines are not exhaustive and will not cover the full diversity of metrology applications, but they should give greater clarity to the NMSA-1 standard.

The NMSA standard does not rigidly lay out what a working metrologist should be able to do or what qualifications they need to perform their roles to a defined standard. Metrology is applied so broadly across industry, academia and beyond, that it is unrealistic to develop a single simple standard. The NMSA-1 framework defines key skills and competencies that a person working in a metrologically-based role and their employer can apply to their individual working situation. Skills appropriate to the metrologists role can be selected from the relevant ones within the NMSA framework. NMSA-1 also allows an individual or their employer to develop a progression of knowledge to enhance their working practices and build a career in metrology.

NMSA-1 defines 4 levels of skills across 6 core subjects. Each subsection within the core subjects has a defined expectation of what each skill level should have as a good working knowledge of and should be able to demonstrate within their normal working routine. The general approach to working levels of expertise can be considered as follows:

- **Foundation Level**
  This is the stage that could be described as 'metrology for non-metrologists'. These are individuals who need a working knowledge for aspects of metrology, but who don't routinely take measurements. The level should provide sufficient knowledge for those individuals to understand what a metrologist is reporting to them and for them to take decisions based upon the information that they have been given. This level may also provide a foundation, or awareness, for individuals starting a career in Metrology as a basis to progress onto further levels.
- **Level 1**
  This is for practicing metrologists who work under supervision. This could be those taking measurements 'full time' or taking in process checks within their normal working practices and conducting self-validation checks on their results before reporting. For these individuals they would be expected to be following a defined process that has been created by someone with higher level metrology skills. Individuals would also be expected to conduct validation exercises but not the analysis for routine and new instrument studies.
- **Level 2**
  This is for more experienced and more senior metrologists. There is an expectation that there will be some direct 'hands-on' metrology in this role but for measurement tasks that are not routinely measured or that are not conducted on automated inspection equipment. This level is expected to create measurement processes from engineering drawings/CAD models and to be able to devise appropriate measurement routines to accurately capture

the engineering requirements. Individuals would also be expected to conduct validation exercises and also the analysis for less-complex cases of routine and new instrument studies. This is also potentially a supervisory role within a metrology area, checking and in some instances, approving the work of a Level 1 metrologist before the results are published.

- **Level 3**
  This level is for metrologists that are expert within their organisation, and whilst some 'hands-on' activities could be performed, they will be developing measurement methods, local standards, processes and procedures for others to follow. They will be consulted when results are unexpected or ambiguous and will lead the decision making. It is also likely that they will have some responsibility for strategic planning for the facility and will be identifying, specifying and supervising validation studies for the assessment of new instruments and analysing results from complex routine assessment studies.

The descriptions for the levels contained within the NMSA Standards are not exhaustive. It is the responsibility for an organisation to define the responsibilities for roles associated with metrology and ensure individuals within those roles are appropriately trained. The definitions in NMSA-1 and -2 enable decisions on responsibilities to be made but organisational requirements drive a flexible approach to an individual's role.

The levels are designed to allow flexibility within the different roles that an organisation may have. Whilst a broad expectation can be assumed around the skills and competencies associated with a particular level, it is not rigidly applied. For example, an individual working in a role described as a 'Level 1 Metrologist' may have operational requirements that need them to be qualified to Level 2 and other requirements that only need them capable of working at a Foundation Level. Similarly, individuals in roles demanding higher technical skills may have a requirement for competencies across all of the levels.

The levels and their associated descriptions also allow an individual or their line-management to plan technical development training and set targets to ensure both personal and organisational objectives are met. The flexible, modular nature of this standard means that training requirements can precisely be adapted to organisational needs as it is recognised that metrology is a large and diverse occupation.

The basis of NMSA-1 is to establish recognised skill levels across the entire field of metrology. The core subjects are key foundation skills for any metrology practitioner, whatever industrial sector or field of academia etc. they work in. The requirements for an individual will vary dependent upon their role and the demands of the metrology work they do, but the knowledge required will be duplicated across many other roles across a wide range of industry.

NMSA-2 is designed to address the particular skill requirements associated with different measurement tasks. These are planned to be published in sector-specific sub-standards as this allows focus on a much smaller set of measurement instruments. An added benefit of this approach is that similar industrial sectors perform similar measurements using similar instruments, for example, flow measurement skills are applicable to Oil & Gas, Water Supply, Bulk Chemical production and other industrial sectors.

The core subjects are split into two sections;

- Fundamental Skills
- Skills aligned to a typical metrology process

The six core subjects are;

- **Fundamental Skills**

    - Metrology Fundamentals: Metrology skills that are used across any metrology activity (e.g., traceability, uncertainty).
    - Enabling Skills: Non-metrology specific skills that are essential to support the defined skills (e.g., mathematics, statistics).

- **Skills aligned to a typical metrology process**

    - Measurement Requirements and Planning: Defining the requirements for the measurement to be conducted and planning how it will be achieved.
    - Realisation of the Measurement System: Creating a measurement system to achieve the defined measurement requirements.
    - Measurement Systems Analysis (MSA): Demonstrating that the measurement system meets the defined requirements and is capable of providing a reliable measurement result.
    - Measurement Operations and Reporting: Operating the measurement system and maintaining its performance over time, including independently assuring its performance.

The core skills framework is laid out to mimic the process of a measurement from concept through to routine operations. In the beginning is the key background information needed, both for metrology and the wider information required to enable the metrologist to perform their responsibilities. The process flow starts with the high-level planning, what is required by the customer and how could the measurements be realised. The detailed planning follows and determines the equipment, method, resources, materials and environmental considerations for the measurement to be taken. MSA determines the robustness the measurement system. Finally, the system that assures the repeatability and quality of the measurements over the lifetime of the measurement system are established and implemented.

There cannot be a single definition of what skills are required to perform the duties of a metrologist. Even within a single metrology function in an organisation there will need to be different requirements defined for individuals performing similar roles. The experience and expertise of individuals performing in their role will also influence the role requirements defined against the NMSA-1 Core Framework.

NMSA-1 Core Subjects

NMSA-1.1 Metrology Fundamentals

Metrology requires precision and consistency from its practitioners, whatever field of metrology is being performed. There is also a need to ensure that those peripherally involved in metrology also have a working knowledge of the concepts and language used by metrologists to better understand the information flows to and from metrologists.

Metrology is a scientific discipline and underpins other sciences through its custodianship of the definitions of units of measurement used in academia, industry, and everyday life. This standardisation ensures consistency but also demands that metrologists work to those standards. The Metrology Fundamentals are key elements of what it means to be called a metrologist, whatever field that individual is practicing in and someone cannot be called a metrologist without having good knowledge of the fundamentals. An individual can spend their whole working life taking measurements but without the underpinning fundamental knowledge they could be considered to be little more than 'data-gatherers'.

NMSA-1.1.1 Metrology Terminology

The use of precise and consistent language is key to communication of a metrologist's work and interaction with the rest of their organisation and beyond. This section ensures that an individual understands the major elements of metrology and its terminology and is able to describe what they are. This consistency is key to collaboration within and beyond an organisation and underpins key aspects of life such as international trade and academic progress.

The world's governing body for metrology, the International Bureau for Weights and Measures (BIPM) has created the International Vocabulary of Metrology (VIM)[1] to ensure consistency of language and terminology. It is expected that metrologists use language in their formal communications that accurately reflects the technical definitions contained within the VIM. At more senior levels, metrologists should be able to explain the terminology in layman's terms when communicating with all operational levels of an organisation.

Furthermore, metrologists should be able to bridge between the formal technical language defined in the VIM and technical terms or colloquialisms used in the organisation or sector that they work in.

NMSA-1.1.2 Units of Measurement

Metrology is fundamentally interlinked with the International System of Units (SI) and strives to ensure that measurements that are taken can be traced back to the national and international standards for the appropriate unit. Whilst measurements can be taken using derived SI units or using other units common in their industry or country, e.g. dimensions in inches is a common method of specification in the aerospace industry, they too are derived from the base SI units through conversion factors.

For metrologists, it is essential that they have a good understanding of the base and derived SI units (and the link to their fundamental constants[2], e.g. the metre definition is based on the speed of light) and communicate units correctly in their practices include verbal and written communications.

[1] JCGM200 (International vocabulary of metrology – Basic and general concepts and associated terms (VIM) and reference.

[2] NPL Resources: SI Units

Poor understanding and communication of units can have significant implications, such as the loss of the NASA Mars Climate Orbiter where one element of the spacecraft was design in metric units and another in imperial units and mistakes in conversion factors led to the complete failure of the mission[3].

NMSA-1.1.3 Traceability

A core principle of metrology, one that is fundamental to the ability to compare measurements between products and instruments, is traceability. That is being able to trace a measurement through an unbroken chain of uncertainties back to the SI units via the national and international standards. This not only relates to calibration, but also to the process for individual measurements.

Traceability allows confidence when comparing measurements taken between different instruments, and is a key component of trust in trade. It is based on a 'pyramid' of measurements, where the validity of measurements taken by an instrument or measurement device are verified within defined limits by comparing the results for an artefact of known provenance against measurements taken on the artefact using an instrument of verifiable higher accuracy. These verified artefacts can be traced up to the pinnacle of the pyramid to measurements taken through a continuous chain of verification measurements back to the national measurement institute and hence to the international standards.

NMSA-1.1.4 Calibration

The key element to traceability is the establishment of a hierarchy of calibrations that reach up to the national standards for that measurement. Calibration provides the evidence that details where in the traceability chain that measurement is taken and how it can be related to the national standard.

For metrologists, detailed understanding of calibration and calibration processes is crucial to ensure trust in their measurements. They need to understand how calibration is undertaken and how to ensure compliance to the national and international standards governing calibration processes. They will also need to understand the frequencies of calibrations and how to conduct interim verification exercises on their instruments to ensure calibrations remain valid.

NMSA-1.1.5 Uncertainty

A core principle in metrology is that the 'true' value of a measurement can never be determined, and that the difference between the measured value and the true value is known as uncertainty. As there are many factors that influence the measured value, such as temperature and humidity, and these vary over time, these factors are grouped together to create an uncertainty statement for the measurement and should be quoted with the measured value when reporting.

For metrologists, the detailed knowledge of the factors influencing the measurement and their control is critical, particularly if the measurement forms part of a repeated task. Analysis of the factors and their potential influence on the measurement lead to the creation of an uncertainty budget which can be quoted, along with an indicator of the confidence level that the uncertainty statement is robust.

Uncertainty analysis and methods to construct an uncertainty budget are written into international standards and metrologists are expected to have a working knowledge of these documents. The

[3] Simscale Blog: When NASA Lost a Spacecraft Due to a Metric Math Mistake (Downloaded 08/08/2023)

Evaluation of measurement data — Guide to the expression of uncertainty in measurement[4] (GUM) published by the BIPM, provides the internationally recognised authoritative standard for uncertainty.

NMSA-1.1.6 Key Standards in Metrology

Much of the work of a metrologist revolves around standardisation, i.e. standard methods of working to reduce uncertainty, etc. along with the key formal standards that allow confidence in measurements particularly when exchanges occur between organisations. The metrologist is expected to have working knowledge of the relevant standards applicable to their area of responsibility and the industrial sector in which they work, and to adhere to those standards as a matter of routine in their daily work.

NMSA-1.1.7 Legal, Regulatory, Commercial Considerations

Metrology adds confidence and authority to measurements, and as such is expected to enable organisations to comply with their legal, regulatory and commercial responsibilities. Metrologists should ensure their work is in line with the appropriate compliance requirements and when audited, be found to be compliant.

Failure to maintain compliance could lead to the metrologist's employer being prosecuted or suffering other commercial loss. The metrologist is expected to be familiar with the broader implications of their work and to ensure that they work within corporate, national and international standards and support periodic audits of their work.

NMSA-1.2 Enabling Skills

Metrology as a science does not stand alone from the rest of the scientific world. It utilises the same fundamental knowledge as a basis for many of the metrology specific tasks as many other branches of science. As the purpose of the core framework for skills is to define the key skills for a metrologist, the NMSA document does not seek to redefine what a metrologist should know as background knowledge, but does lay out significant areas of background knowledge that metrologists are most likely to use in their work. This section is not comprehensive, and each organisation will have its own requirements for metrologists' background knowledge. The NMSA document does define the general areas of background knowledge appropriate to the operating level for an individual but it is the responsibility of each organisation to precisely define what knowledge is appropriate.

NMSA-1.2.1 International Standards

This section covers more general international standards that metrologists work within. For example, these could be generalised standards such as ISO9001 Quality Management Systems or ISO14001 Environmental Management Systems or sector specific standards such as IATF 16949 within the automotive industry as an application of quality management standards and the equivalent in the aerospace industry AS9100.

Metrologists must work within the standards applied to their organisation and understand how their work complies with the relevant standard. Standards applied can also be technical rather than

[4] JCGM 100:2008 Evaluation of measurement data — Guide to the expression of uncertainty in measurement

sector specific to cover aspects of the metrology technology that they use, e.g. when radiation is being used they must ensure they comply with the UK IRR17 Regulation[5].

NMSA-1.2.2 Mathematics for Metrology

Metrology requires all practitioners to be numerate and understand the fundamental mathematical principles that underpin the operation of the instruments that they use, and the analysis methods applied to ensure their results are meaningful. These principles are not unique to metrology, but metrology practitioners must be able to apply appropriate knowledge of mathematics and statistics to the measurements taken as part of their role.

For the 'customers' of metrology, they too need a basic understanding of the underlying mathematics and statistics. This will enable them to set the right conditions for measurements to be taken and apply their own critical analysis to the results and analysis.

NMSA-1.2.3 Physical Principles of Measurement

For all customers and practitioners of metrology, a good knowledge of the physical methods of how measurements are taken is key to understanding what the measurement data and analysis is reporting. For metrologists, this is further enhanced by understanding the SI units that are being used to report and the factors that contribute to the uncertainty statement associated with the instruments used and measurement results.

The understanding of the interconnectedness of multiple metrology instruments that contribute to the measurement result enables better analysis and judgement to be applied. For example, knowing the air temperature of the local environment that the measurement was taken in will help to inform decisions regarding the potential dimensional change of a sample and the influence of the coefficient of thermal expansion for the material that the sample is made from.[6]

NMSA-1.2.4 Data Analysis

Similarly to mathematics principles, metrology requires practitioners and their customers to have an understanding of data analysis methods to provide greater context to the measurement results. A single measurement result cannot fully convey the detail of how that result came to be. A series of measurements and detailed analysis can give much greater insight than just the measurement results taken in isolation, and so it is essential that data analysis methods are understood and correctly applied.

Data analysis is most obviously applied to measurement results, to understand the information provided and the context in which that information was gathered, for example, measurements taken from samples manufactured over a period of time will give better insight into the variability of a manufacturing process than measurements taken from a large batch of samples gathered in a short space of time.

Data analysis is also used to prove the efficacy of the measurement process itself. Whilst tools and techniques applicable to metrology are covered in greater detail in NMSA-1.5, understanding of the statistical analysis methods is very useful to have before conducting or evaluating Measurement Systems Analysis studies when assessing data gathered in a measurement exercise for robustness.

[5] Working with ionising radiation. Ionising Radiations Regulations 2017. Approved Code of Practice and guidance

[6] Wikipedia page on Thermal Expansion for a longer explanation of CTE

NMSA-1.2.5 Design of Experiments

Following on from the understanding of data analysis methods, Design of Experiments (DoE) tools provide methodologies to conduct investigations into the influence of variables on a system in the most efficient way and without conducting an exhaustive range of experiments. The DoE frameworks allow the investigation of the impact of multiple different factors—changed simultaneously—on an experimental process. DoE also identifies and explores the interactions between those factors.

The DoE methods can provide insight into investigations in issues from the trivial through to issues with complex multi-stage processes and a significant number of variables. The design of DoE studies must not only include the investigation plan (i.e. which variables are changing for each repeat of the experiment) but also the analytical methods to be used to evaluate the overall study. All metrologists must ensure that they know their part within a DoE study, from ensuring a study is run correctly, through robust gathering of data, to initial design and subsequent analysis of results; good metrology practice will ensure the best possible analysis from the study.

NMSA-1.2.6 Quality Systems and Tools

There are a wide range of well-known analytical and experimental tools that can be applied to identify the root causes of quality issues and help to determine potential methods for resolution. These include '5-whys?', Pareto Analysis, basic charting, regression analysis, etc. These are as applicable to identify and resolve issues within metrology as metrology can be used to help identify and resolve issues in manufacturing and other scenarios.

With a good understanding of the basic tools, a metrologist can identify issues and resolve them within the metrology environment and before they become significant problems to the customers of the measurement. Furthermore, the knowledge gained from resolving issues with their measurements can be used to prevent the mistakes being repeated in the future. This approach of continuous improvement will help to strengthen the practices of the metrologist and continuously build trust in the results they report.

NMSA-1.3 Measurement Requirements and Planning

This section covers the tasks necessary to achieve robust measurements of a product, effectively laying the foundations for the future measurement task. A significant proportion of these skills require the ability to converse with a product or process designer and to understand their functional requirements along with the tolerances that make the product 'good'. The metrologist will have to take the requirements and develop the planning for the measurement system to achieve a realistic accuracy utilising the most cost-effective equipment and delivering results in an appropriate timeframe, in other words, the classic Cost-Quality-Time compromise.

For the metrologist, the definition of the measurement plan requires knowledge beyond the metrology field itself. Whilst it is essential to try and satisfy potentially conflicting demands, background knowledge of topics such as manufacturing processes and material properties will help to deliver a robust measurement plan. In many cases, the metrologist will have to lead the conversation and explain topics such as the way particular measurement instruments work and measurement uncertainty to ensure that an acceptable solution is achieved.

NMSA1.3.1 Requirements Capture & Definition

The requirements capture and planning should develop a detailed plan to robustly evaluate product, process or service conformity throughout their manufacturing process up to the point of delivery. The verification method will need to provide accurate data with a low level of uncertainty (a rule of thumb is 'one tenth of the tolerance') whilst being able to achieve the measurement at a low cost and in a timeframe to ensure that the results can be analysed and actioned before the customer is aware.

The functional requirements of the product, process or service should be interrogated and understood. Ideally these are expressed in a tolerance scheme that defines the maximum allowable variation from the nominal (ideal) condition. If defining the requirements for a component part or sub-assembly from within a larger, more complex assembly, then it is also necessary to understand how the components/sub-assemblies mate to each other and what the outline assembly sequence is.

At this stage it is also essential to understand the condition of the parts when they reach the potential location for the measurement to be undertaken. This could require planning for the parts to be cleaned before measurement, they may require acclimatising to the environmental conditions of the measurement location (also called soaking) and flexible parts may need to be supported to be able to give a measurement result that is meaningful to the next level of the assembly process. For some parts it may be necessary to measure them in an 'as manufactured' condition rather than against the nominal engineered condition as they may only adopt their final shape once they have been assembled into the larger object. Similarly, it may be necessary to develop plans for parts to be checked at intermediate stages of manufacturing to detect issues before subsequent manufacturing operations add significant value to the parts which would be lost if early errors are not detected, for example, raw castings may be checked to ensure there is sufficient material present so that machining operations do not cause new errors to be introduced.

The measurement plan may also have to consider conditions from the lifetime of the product's manufacturing or its service life. The earlier that these are taken into consideration, the easier they are to implement.

NMSA-1.3.2 Design for Measurement

Metrology can have a significant influence on the design of new products, processes and services. The first area of influence is to ensure that there is a feasible metrology solution to evaluate the conformity to specification for all defined features. A suitable metrology solution must be place from the first point that the product, process or service is established after the design or planning stages to ensure that the specification is achieved. In some instances, a new metrology solution will be required to achieve both checking conformity to specification, but also to the accuracy and timeliness that is demanded.

The second benefit of involving metrology functions in the design and planning phase is where there is existing measurement data from a similar product, process or service. Analysis of this data can provide realistic ranges for variation and confirmation that the proposed measurement process is robust. By utilising existing knowledge, development of specifications can be shortened and measurement planning can be expedited.

NMSA-1.3.3 Determination of Measurement Methods

In many organisations, metrology is considered to be an overhead as there is often no direct correlation between good metrology and the cost benefits of preventing poor quality products reaching the customer. Even in organisations with a good understanding of the cost benefits, it is sensible practice to try and minimise the costs associated with gathering robust measurement data. Advance planning can aid this by supporting the development of compromises in the product, process or service being developed and looking at the total costs associated with introducing this to the organisation and maintaining quality standards for the lifetime of the proposed development.

The simplest way to specify measurement methods is to utilise existing facilities, equipment and software to take the required measurements and conduct analysis. Feasibility studies will need to be undertaken to ensure that this method is able to meet the specification and that there is sufficient capacity to undertake the required measurement plan.

If it is infeasible to use existing facilities, then alternative provisions must be made and put in place in line with the launch plan requirements. The metrology function will need to source, install and conduct verification analysis exercises for the new instrument, and often make contingency plans as some metrology instruments are on extended delivery schedules.

NMSA-1.4 Realisation of the Measurement System

The realisation of the measurement system is principally concerned with turning the measurement systems requirement into reality. When a new product, process or service is being introduced the measurement system must be in place and validated before the launch to assist with the validation and preparation activities. Ideally, the measurement system will be in place in time for the first time any physical pre-launch prototyping or testing is undertaken, although it is usually necessary to also validate the measurement system itself using the pre-launch prototypes.

It is essential that the planning for realising the measurement system is incorporated into the overall launch plan and that sufficient time is allowed to enable the measurement system to be validated along side the maturation of the product, process or service prior to launch. There is a significant level of risk associated with not conducting robust measurement system validation prior to launch as the data produced will not be of the highest quality achievable and will provide less satisfactory insight into the performance of the prototypes.

NMSA-1.4.1 Machine/Equipment

In order to properly predict how measurements can be taken, the metrologist requires a good technical understanding of the instruments that are likely to be used. The knowledge required includes how the instrument operates, its methods for capturing the measurement, its strengths and weaknesses and its major sources of uncertainty. This information will help select the best method and instrument to capture the required measurement data.

Selecting the right equipment is key to establishing a robust measurement system. By understanding the potential sources of error and the potential verification processes the metrologist will be able to establish the best compromise of performance, cost and speed to deliver high-quality data and support robust decision making. Once measurement systems are committed to it can be expensive and time-consuming to change if verification proves that the measurement system is not capable of achieving its required performance, so application of expertise is essential.

NMSA-1.4.2 Method

The method of measurement is important in taking accurate measurements, particularly if those measurements are repeated across a number of samples. When implementing a measurement system, it is key to ensure that the proposed method is able to deliver both the required data and that consistency can be achieved. For regular measurements, process documentation should clearly define the full method of measurement for a sample, from receiving and preparing the sample, through taking the measurement and including post-measurement activities such as despatch and data analysis and reporting.

Standardisation is an important component and variation in the method of measurement contributes to the overall uncertainty. Ideally, methods should be validated before the formal measurement process is used and periodically checked to ensure that the desired consistency is still being achieved.

NMSA-1.4.3 People

All measurements where the data is to be used to support a decision should be taken by a competent person. Even simple measurements using hand-held instruments require a degree of skill to ensure that the measurement is as robust as possible, for example, ensuring callipers are correctly aligned to the surface of the object being measured.

For more complex measurements, there is naturally a requirement to ensure that the person taking the measurement is sufficiently skilled. This assessment of the skills should cover the practicality of taking the measurement, it is insufficient for an individual just to hold a certificate. For some measurements such as those using non-destructive testing instrument, there are restrictions on who can take the measurement and they must hold time-bound certification of their competence. Similarly, where the measurement influences critical product functions or product safety when used by the customer, there is a greater requirement to ensure the individual taking that measurement is qualified and competent.

NMSA-1.4.4 Preparation for Measurement

For a metrologist to give the best feedback based on the results of the measurements that they have taken, they need to fully understand the impact that the various materials, manufacturing and supply methods have on the product, process or service that they are measuring. These precautions could include cleaning, special handling arrangements and personal protective equipment needed for the metrologist. In some cases, these preparations could be more complex depending upon what is being measured, for example, chemical etching to highlight the material structure under investigation. These preparations should be standardised so that they become normal, repeatable actions each time a new measurement is required and as such should be part of the standard operating instructions.

NMSA-1.4.5 Environment

Metrologists need to understand the effect that the environment where the measurement is being taken has on the results of that measurement. For example, every material expands and contracts due to changes of temperature. The metrologist also needs to understand the rate of change of the material and how this relates to the expansion or contraction of the measurement instrument being used. For high precision measurements this could mean that there is a requirement for climate controlled room to be used and that products need to acclimatise before the measurements can be taken.

The requirements and allowances for environmental conditions need to be understood before measurements can be routinely taken, and where a controlled environment is utilised, environmental sensors will need to be deployed and monitored as part of the measurement operation. Furthermore, the metrologist will need to react to the conditions and their changes so that the measurement results are as robust as possible.

NMSA-1.5 Measurement Systems Analysis

Measurement Systems Analysis (MSA) is used by metrologists to demonstrate that the measurement system meets its defined requirements and is capable of delivering routine results to the necessary precision. There are a number of approaches that can be used and some industrial sectors have clearly defined and widely recognised methods that can be adopted (e.g., the automotive industry uses the MSA model as part of ISO / IATF 16949[7][8]). All approaches use forms of statistical analysis to predict the potential variability in measurements and assess their suitability to provide robust data to report.

MSA is a key tool underpinning metrological practices and many organisations have standard methods to follow either internally or as a condition for their supplier to comply with before initial production deliveries can be accepted. Metrologists at all levels need to understand the importance of MSA on their work and how to run studies to the standards appropriate for the industrial sector that they work in.

NMSA-1.5.1 Selecting the Appropriate Analysis Tool

There are many methods for conducting MSA studies. They are reliant on having enough samples to reflect the potential range of variation likely to come from the product, process or service. The choice of study will reflect the availability of samples and how representative they are of the norm and the metrologist will have to ensure that the analysis provides useful data on the efficacy of the measurement process.

The design of the study will take into consideration the maturity of the product, process or service and the measurement system itself. For example, if the measurement system design required a new instrument, the study design will need to reflect the limited knowledge of the full capabilities of the new instrument.

NMSA-1.5.2 Conducting the Study and Analysing Results

The measurement study is a controlled exercise and needs to be treated appropriately. The measurements must be taken exactly in line with the design of the study otherwise the analysis will be compromised. This demands that the study is adequately planned and prepared for, that measurements are taken in the sequence specified and the analysis follows the planned method (even if the analysis is conducted using a software package).

[7] IATF 16949 MSA webpage
[8] Wikipedia page on Measurement Systems Analysis

NMSA -1.5.3 Measurement System Acceptance

The final stage of MSA is to make a judgment on the fitness for purpose of the measurement system under review. The results and judgement must be reported in a consistent manner to enable clear communication and understanding beyond the metrology function.

Key to the acceptance is understanding of the detail within the results, particularly if the MSA study failed. The understanding of factors such as the influence of one operator, marginal results and areas of failure will lead to potential improvements being identified and introduced.

NMSA-1.6 Measurement Operations and Reporting

Once a measurement system has been introduced, the metrologist has an ongoing task to operate the system and maintain (or improve) its performance. The first element is to maintain the consistency required when taking the measurements, particularly as complacency can intrude into familiar and repeated tasks. Whilst there should be a standard operating procedure governing how the measurements should be taken, it is human nature to look for short-cuts and whilst on the surface these may not influence the measurement results, they may have a longer-term influence that is harder to detect.

The metrologist will also need to independently assure the performance of the measurement system over time. Some of the variables in the uncertainty statement may be on long-term cycles, for example, the external weather varies through the seasons and this may have an unknown influence on the measurement system. Results from the measurement system will need to be monitored and ideally a periodic verification exercise will be conducted to assess the continued efficacy. The verification process may not be as detailed as a full MSA study, but will pick up longer-term issues such as machine wear or drift before they become a significant problem to the accuracy of the results.

NMSA-1.6.1 Conduct Measurement in a Structured Manner

Ensuring consistency of measurements is vitally important to maintaining the accuracy of measurement system and retaining trust in the data provided. The metrologist operating the instrument within the measurement system must ensure that the standard operating method is followed meticulously every time a measurement is taken and that data is analysed and reported consistently within the reporting template. The metrologist should also be able to identify when issues arise before the results are reported and ideally the standard operating method will include instructions for when abnormal results are recorded.

Over time opportunities for improvements to the measurement system will arise. Some of these will come from familiarity with the system and equipment and should be incorporated following experimentation to ensure that the validity of the measurement results is not adversely affected. Opportunities will also arise from validation exercises and process audits or when adverse results are recorded and the root cause is identified. These too can be incorporated into the standard operating method after suitable analysis to ensure that the results remain trustworthy.

NMSA-1.6.2 Analysis and Reporting of Measurement Data

For a metrologist, data analysis is just as much a part of the measurement system as taking the measurements using the instrument. Just reporting the results of a single measurement can identify if a product, process or service is within specification limits, but much more detail can be derived from further analysis of the data. For example, if the measurement process of a stamped part takes a series of measurements at intervals along one flange, the metrologist can compare results of this group of measurements and provide insight into whether the flange is offset but effectively parallel to the desired shape, angled or wavy.

Measurement analysis and reporting should be conducted in a standardised manner to ensure consistency of reporting from measurement to measurement and to identify where adverse results have been recorded. Reporting templates should be developed in conjunction with the 'customer' of the data to ensure that this is understandable and fully supports any downstream usage of the data.

Where measurements are taken in a regular manner supporting the long-term operation of a product, process or service, then analysis and reporting should also consider the result against measurements taken previously and provide insight into any potential issues or trends that have been detected.

NMSA-1.6.3. Decision Rules Using the Measurement Result

One of the key tenets of metrology is "no process without measurement, no measurement without analysis, no analysis without action!". For routine measurements taken as part of the measurement system for a product, process or service, the data analysis and reporting can be made more efficient by the development of decision rules. These rules can define which results can be classified as pass or fail or what action to take if a result is either a marginal pass or a marginal fail against the specification limits.

The decision rule will always contain a clear classification against a defined set of criteria for the metrologist to follow. These rules can include 'take no action' as this is a defined action suitable even when a result is determined to be a failure but has been agreed as not significant by the customer even though it is out of specification, for example, a part marginally out of specification could be matched to another part in the assembly with a measured result that will ensure the assembled condition is within specification limits and no detriment to product performance.

The decision rules must be developed with the consumer or end-user of the product, process or service as well as considering the next stage within the sequence that delivers it to market. These requirements may often be conflicting and a balance needs to be struck so that economic performance, functional performance and customer satisfaction are achieved.

Version History

Version	Reason for Issue	Date
1.0	First Issue	20/12/2023