ICAR

THE GLOBAL STANDARD FOR LIVESTOCK DATA

ICAR Accuracy Task Force Report

Author: Accuracy Task Force

Final: 30 September 2016.

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1 Recommendations

1. The ICAR Guidelines be expanded to include guidelines for evaluating the benefits arising from each of the uses of animal recording data with special consideration to the relationship between the benefits from each use and the accuracy of the original recording data.
2. Review ICAR Guidelines to ensure identification systems used for animal recording accurately link each animal to its phenotypes, genomic information, environments, parents and contemporaries.
3. ICAR guidelines for all measurements include tools to establish and publish the accuracy of original recording data relative to the relevant gold standard.
4. Establish the accuracy of the animal recording information systems that collect and store original data and provide information for use in decision-making.
5. Members implement continuous improvement processes to ensure their animal recording business provides valuable information for decisions related to animal: breeding, management, product quality, and health.

2 Introduction

This is the report from the Accuracy Task Force (A-TF) established by the ICAR Board in November 2013. The membership of the A-TF was finalised in the third quarter of 2014 and work commenced in the fourth quarter of 2014.

This final report was received by the ICAR Board at its meeting on September 27th 2016.

Terms of Reference

ICAR established the A-TF in response to a growing concern that it was following a philosophy and using tools to address questions of accuracy that were no longer fit for purpose. The challenges ICAR and its members are facing arise from a plethora of new devices for gathering recording data on farms and in-line measurements during, for example, milking. Some of these devices are less accurate than conventional recording but make up for this loss of accuracy by providing many repeated measures.

The objectives of the A-TF[1] are to:

a. *Develop a scientifically sound philosophical basis for ICAR to use in establishing accuracy guidelines for the collection of animal recording data that is incorporated into information services that support:*

i. *breeding,*

[1] Terms of Reference for ICAR Accuracy Task Force. Author: Brian Wickham. Dated: 11th July 2013.

ii. *farm management,*

iii. *traceability/supply chain/quality assurance,*

iv. *health/welfare.*

b. *Provide statistical tools and guidelines, for use by ICAR Groups in establishing accuracy guidelines relevant to their particular area of expertise.*

In the course of our work we have also identified some case studies that illustrate the use and value of particular tools.

Members

Members of the A-TF are given in Table 1.

Table 1. ICAR Accuracy Task Force – name, country and expertise.

Martin Burke, Ireland, milk recording, recording devices and quality systems
Kees de Koning, Netherlands, recording device testing, and statistical systems.
Albert De Vries, USA, precision systems, research and management information
Bevin Harris, New Zealand, statistics, animal breeding and recording systems
Esa Mäntysaari, Finland, statistics, animal breeding and research
Filippo Miglior, Canada, milk recording, research and animal breeding
Harrie van den Bijgaart, Netherlands, milk analysis, milk recording and analytical systems
Joel Weller, Israel, statistics, economics, research and animal breeding
Brian Wickham, Ireland, Convenor
Karl Zottl, Austria, Field use of quality data

Process

The process by which this report has been developed consisted of a series of meetings (Table 2) at which ideas were considered, having been distributed by email in advance of each meeting. The ideas were discussed, issues identified and action plans agreed. Decisions were taken by consensus.

Table 2. Accuracy Task Force meetings.

Date	Type of Meeting
Wednesday 5 November 14	Telephone conference
Tuesday 9 December 14	Telephone conference
Monday 12 January 15	Telephone conference
Monday 9th March	Telephone conference
Monday 13th April	Telephone conference
Monday 18th May	Telephone conference
Monday 1st June	Telephone conference

3 Philosophy

In this section we outline a philosophy on accuracy that we believe is most appropriate for ICAR and its members. In the course of our considerations we have made a number of recommendations that we believe best capture the key points of the philosophy. These recommendations are given at the end of the relevant sections and are repeated in section 1 above.

Terminology

Some of the terminology associated with accuracy relevant to the activities of ICAR has been defined through international convention as summarised in Table 3.

Table 3. Sources of definitions related to accuracy and relevant to the activities of ICAR and its members.

Definitions	Source	Reference:
Related to guidelines for expressing the uncertainty of measurement (GUM).	International vocabulary of metrology – Basic and general concepts and associated terms (VIM). Published by International Bureau of Weights and Measures (BIPM).	http://www.bipm.org/en/publications/guides/ Accessed 25th Feb. 2015.
Related to accuracy of measurement methods and results.	Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions. ISO 5725-1.	https://www.iso.org/obp/ui/ - iso:std:iso:5725:-1:ed-1:v1:en Accessed 25th Feb 2015.
Related to all aspects of disease testing and diagnosis.	OIE Terrestial Manual 2013.	http://www.oie.int/en/international-standard-setting/terrestrial-manual/access-online/ Acessed 3rd March 2015.

For convenience the key definitions of relevance to ICAR have been extracted from these sources and are attached as appendix 1. However, this literature is focused primarily on the original measures and as explained below this is only one of several considerations in determining the accuracy of the information resulting from animal recording activities.

In the body of this report we have attempted to use simple readily understood terms and to provide explanations in the text as needed.

ICAR members operate recording systems

ICAR's full members are organisations who operate recording systems for farm animals – mainly cattle, sheep and goats.

Recording systems involve a multi-step process, which includes some or all of the following steps:

a. identification of a target group of animals for which records are to be collected

b. determination of the extent to which the group of animals share the same environment in terms of nutrition, management and exposure to diseases

c. identification of the animals within the target group for which records are not collected

d. identification of an animal

e. taking of a sample from the animal or from its production (milk, tissue, …)

f. the measurement (which by definition includes observations, that is, measurement by visual assessment) of one or more attributes of the animals, for example weight and milk yield, or the taken sample

g. validation of the measurement and its association with an individual animal

h. storage of the results in a database

i. extraction and combining of data from databases to compute genetic evaluations which are stored back into databases and distributed to the breeding industry for use in breeding decisions

j. extraction, statistical analysis, formatting and distribution to herd owners of a wide range of reports

k. use of the reports by the herd owner to make farm management decisions (breeding, culling, drying-off, nutrition, disease control, …)

l. extraction, statistical analysis, formatting and distribution to the wider industry and community, nationally and internationally, of reports which provide comparative information over time, over organisations, over countries of animal production characteristics (breeding, farm management, supply chain and health).

The recording process as operated by ICAR members is summarised by Figure 1.

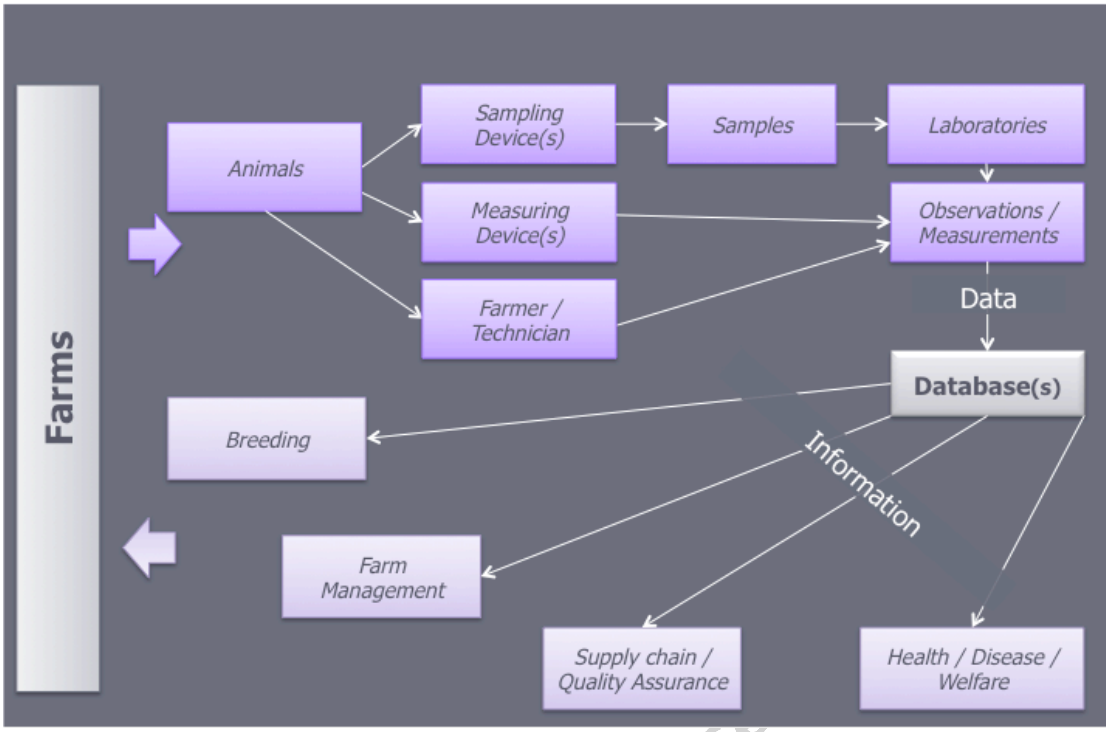

Figure 1. The recording process as operated by ICAR members.

The output of recording systems is information for decision making

Animal recording is partly an economic activity and partly a *good practice*. Farmers, recording organisations, industries and societies provide the resources, including funding and access to animals, to facilitate animal recording. The reasons for providing this support include:

a. The *good practice* of having factual information on the performance of individual animals.

b. To provide information which facilitates breeding, culling and a wide range of other farm management decisions by farmers.

c. To provide data which is used for research relevant to animal farming resulting in information that is used by the animal production sector in its decision-making.

d. To provide information which is used by breeding organisations and a wide range of other organisations in developing and providing services to farmers.

e. To provide information that is used by public bodies to design legislation, and to support: quality assurance, public health, animal health and other community wide initiatives.

In short, animal recording is primarily about providing information, which is used in decision-making as shown pictorially in Figure 2. **Recording**, the first step in the process, involves the collection typically of multiple observations and measurements on individual animals over a period of time. The second major step is the **processing** of the resulting data. This step includes a number of activities such as data validation and data storage, which are followed periodically, by the **delivery of information** for use in a range of decisions, the third step. Information delivery includes the combining of data collected over extended time periods from multiple animals followed by an analysis step and evaluation step. The resulting information is the input that used in decision-making. The first three steps incur costs. The consequence of the decisions made is the point where the benefits of recording are realised. These benefits include a combination of desirable outcomes such as: increased income, reduced costs, improved product quality, reduced waste, improved animal health and improved animal welfare.

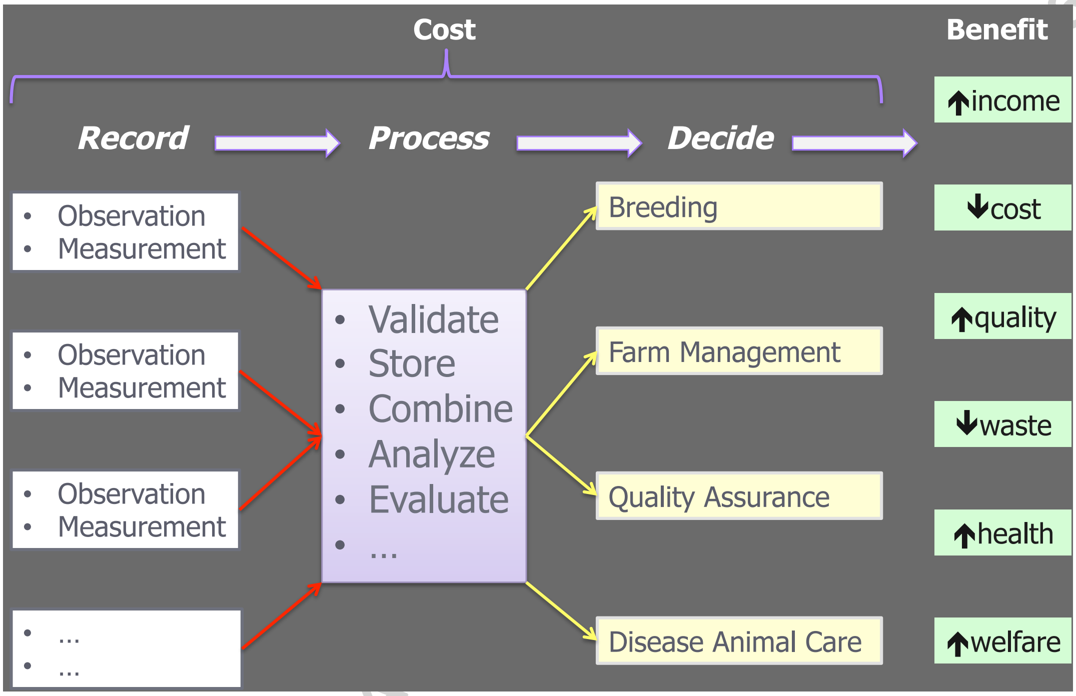

Figure 2. Pictorial description of the recording process showing link between costs and benefits.

Optimal recording system design

Optimising the design and operation of animal recording systems involves consideration of the cost of recording relative to the economic benefit obtained by using the resulting information to make better decisions affecting the future. The value of the information arising from animal recording is determined partly by the relationship between the information and the potential future outcome. The strength of this relationship is measured in different ways, depending on the nature of the information, but generally can be referred to as the *accuracy* of the information for the decision being made.

Data from animal recording is used in preparing information for use in a multitude of decisions. The optimal design of an animal recording system is the one that maximises benefits relative to costs over all decisions. Finding this optimum is a complex task considering:

- **on the benefit side**: the multitude of information products, the multitude of decisions, the multitude of decision makers, the extended time periods over which decisions are made,
- **on the cost side**: the rapid development in recording devices, the rapid development of information processing tools, the rapid development of analytical tools,
- **and** recognising that the same recording data is used in multiple way in different decisions.

For these reasons the design of animal recording systems has tended to involve consideration of a limited range of decisions, and associate benefits, and a limited range of recording systems, and associated costs. This is also reflected in the approach that ICAR has taken towards the subject of accuracy. Initially ICAR and its recording members focused on the use of milk recording data in animal breeding decisions. As dairy cattle breeding objectives have expanded to consider a wider range of traits, and ICAR membership has expanded to consider beef cattle and other species, so ICAR has developed relevant guidelines. For example, for functional traits, conformation traits, beef traits, sheep & goat milk recording, and fibre for sheep, goats, and alpacas. This trend towards a wider range of recording systems covering more traits and more types of animals is being added to by expansion of the services provided by recording organisations into, for example, information services for: farm management, animal nutrition, environmental management, product quality assurance and animal health and welfare (refer to Figure 2). ICAR needs to ensure its philosophy and structure produces the guidelines and services that are most valuable to its members as they evolve.

For these reasons, it is recommended that ICAR place greater emphasis on the benefit side of animal recording by giving consideration to the decisions for which information from animal recording is used to support. This greater emphasis should be in the form of guidelines on the evaluation of the benefits provided by the information coming from animal recording, for each of the decisions that are based on information from animal recording. In this process the significance of the accuracy of the animal recording data will be established and thus provide a firm foundation for evaluating recording tools which differ in both accuracy and cost.

Recommendation 1.

The ICAR Guidelines be expanded to include guidelines for evaluating the benefits arising from each of the uses of animal recording data with special consideration to the relationship between the benefits from each use and the accuracy of the original recording data.

Identification system

The most fundamental element of the accuracy of animal recording is that of animal identification. Accurate recording can only exist where there is a system of uniquely identifying each animal as laid out in the ICAR Guidelines[2].

The uses of animal records: breeding, farm management, quality assurance and animal health all suffer a substantial risk of loss of accuracy due to selection bias if not all the contemporary animals are identified and recorded. Most uses of the records involve some form of comparison between the individual animal and its contemporaries exposed to the same environment. Where contemporaries are not recorded, and thus not included in the comparison, the comparison can be severely biased. Best practice is for all animals to be identified and recorded.

The use of animal records for breeding information requires knowledge of the parentage of each animal. Where this is missing, unknown, or incorrect, there is a loss of accuracy in the resulting breeding information. Recording of parentage is addressed by the ICAR Guidelines[3] and the development of DNA technologies is providing new and lower cost tools for validating parentage of animals. These same tools are also becoming a routine part of quality assurance schemes for meat products as they facilitate tracing of products to their origin. There are important accuracy considerations associated with these uses of animal records.

It is recommended that the ICAR identification standards and guidelines be reviewed to ensure the accuracy of the linkage of each animal to its own records and that of other animals affecting the accuracy of the information provided for the full range of data uses.

Recommendation 2.

Review ICAR Guidelines to ensure identification systems used for animal recording accurately link each animal to its phenotypes, genomic information, environments, parents and contemporaries.

[2] ICAR RULES, STANDARDS AND GUIDELINES ON METHODS OF IDENTIFICATION, ICAR Guidelines 2014, page 9-10.

[3] ICAR GENERAL RULES AND GUIDELINES FOR PARENTAGE RECORDING METHODS, ICAR Guidelines 2014, page 11-13.

Calibration and validation

Measures[4] obtained for individual animals are the original data arising from animal recording activities. In order for these original data to contribute to information for decision making it is essential that their relationship with traits of economic importance is well established. There do exist tools and processes for calibrating and validating these measures.

Typically, calibration involves research in which the measure is compared with a usually much more expensive measure of the *gold standard*[5] for the trait. It is imperative that this research encompasses the range of situations – for example: breeds, nutrition, analytical devices - in which the measures will be made.

The two main considerations in calibration are trueness[6] and precision[7]. Of greatest concern is trueness especially if a lack of trueness is associated with any aspect of the circumstances in which the measure is made. For example, the bias in milk volume is greater in some milk meters than others. Precision is also important but its impact can be reduced by the use of repeated measurements.

Validation typically involves independent research in which the measurement is made using animals that are not part of the calibration data set. These are then compared with the *gold standard*. Where validation fails, the original calibration may be updated, the circumstances in which the measure may be used are restricted, or the measure may fall into disrepute.

It is crucial that the calibrations and validations underpinning all measures used in animal recording are published and thus readily available for independent scrutiny.

> Recommendation 3.
>
> **ICAR guidelines for all measurements include tools to establish and publish the accuracy of original recording data relative to the relevant *gold standard*.**

Animal Recording Information system

Animal recording information systems can be viewed as having two main components: data recording and information production.

<u>Data recording</u> covers the collection and storage of the original data so that it can be incorporated into information products in the future and used in research. The basis for most, if not all, information products using animal

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[4] Which include observations.

[5] Other terms used are: reference value, true value,

[6] Other terms used are: accuracy, bias, validity, and systematic error

[7] Other terms used are: reliability and random error.

recording data is the deviation of each animal's measure from that of its contemporaries, in the same environment. For this reason, the recording system needs to pay particular attention to ensuring:

- Sufficient data is collected to define the environment for each animal,
- Measures are collected on all animals exposed to the same environment, and
- Where it is not practical or economic to measure all animals in the same environment then sufficient steps are taken to ensure there is no bias arising due to selection of the animals that are measured.

A particular risk found in data recording systems is the presence of preferential treatment for some animals within a group that are supposedly exposed to the same environment. Where this occurs serious biases can result, with the consequence that decisions based on the resulting information are seriously flawed[8].

Data arising from animal recording is potentially valuable for decisions being made by parties other than the farmer who was responsible for its collection, many years after the data was originally collected. To facilitate these uses it is very important that extra care be taken during the collection process and that sufficient public, or industry, funding is provided to facilitate this extra care.

Information production covers the process of delivering information that is then used in decision-making. This process is, perhaps, at its most complex for genetic evaluations in dairy cattle where it comprises many steps, uses data from a very large number of sources, including from almost all other countries with populations of the same breed, and produces breeding value predictions that are combined with economic information into selection indexes. The process has become even more complex with the recent inclusion of genomic data derived from DNA chips identifying single nucleotide polymorphisms (SNP) and extensive calibration and validation research studies. The information production process can be as simple as age group averages for cows lactating at the same time in a single herd. In all cases, the key consideration in terms of the benefits that result, is the ability of the information to predict the outcomes that are being chosen between in the decision being made. **The ability of the information to predict the future is thus ultimately the key factor determining the benefit of recording.**

An important component of the animal recording system is the processes by which recorded data and the information produced is **quality assured.** This includes: staff training, staff supervision, data validation, exception handling, change control, and many other contributors to both the cost of recording and the accuracy of the resulting information.

[8] Potential Biases in Predicted Transmitting Abilities of Females from Preferential Treatment. M.T. Kuhn, P.J. Boettcher, A.E. Freeman. Journal of Dairy Science, Vol. 77, Issue 8, p2428–2437. Published in issue: August, 1994

The accuracy of the information arising from data recording is at risk where the funding of data recording and information production is provided by a party with a vested interest in the information outputs. For example, if genetic evaluations came under the control of semen sellers as a result of funding they provided. It is very important that the organisations responsible for data collection and information production are able to operate independently of vested interests.

In summary, animal recording systems comprise five elements that each contributes to the accuracy of the information provided for decision-making. These are, as described above: identification, calibration, data recording, information production and quality assurance. To be able to optimise and improve the benefit to cost ratio of animal recording, it is crucial that the contribution of each of the five elements to the accuracy of the resulting information is quantified and understood.

Recommendation 4.

Establish the accuracy of the animal recording information systems that collect and store original data and provide information for use in decision-making.

Continuous improvement

ICAR's members operate in a wide range of commercial environments that are changing rapidly due to many factors including:

- advances in analytical, information and DNA technologies,
- competition and increased competition for some information services,
- reduction in public funding for activities delivering long term public benefits,
- new knowledge and understanding, and
- the discovery of improvement opportunities.

For these reasons it is imperative from a cost and benefit point of view that animal recording information systems are subject to a process of continuous improvement. These processes typically employ a quality management philosophy as originally espoused by W Edwards Deming[9] that have more recently evolved into tools including Six Sigma™[10], ISO 9000[11] and Lean Manufacturing[12]. These processes focus on ensuring the animal recording

[9] http://en.wikipedia.org/wiki/W._Edwards_Deming, accessed 4th May 2015.

[10] http://en.wikipedia.org/wiki/Six_Sigma, accessed 4th May 2015.

[11] http://en.wikipedia.org/wiki/ISO_9000, accessed 4th May 2015.

[12] http://en.wikipedia.org/wiki/Lean_manufacturing, accessed 4th May 2015.

information system achieves optimal benefit to cost ratios for the customers of animal recording. Their focus includes:

- removing waste thus reducing cost,
- reducing errors, thus reducing cost and improving the accuracy of the resulting information, and
- incorporating new knowledge, and new technologies into information products thus increasing the benefits for the customers of animal recording organisations.

Animal recording organisations need to have processes for ensuring their information services maximise benefits relative to costs. In effect, this means ensuring that any trade-off between cost and accuracy results in improved benefits to costs. ICAR is well placed to assist its members as they pursue these improvement processes by providing guidance and facilitating the sharing of experiences between members.

Recommendation 5.

Members implement continuous improvement processes to ensure their animal recording business provides valuable information for decisions related to animal: breeding, management, product quality, and health.

4 Tools

This section of our report contains a selection of tools that we have identified as being relevant in evaluating aspects of animal recording accuracy. They are divided into three categories: measurement system analysis, recording process optimization, and cost benefits.

Measurement System Analysis - MSA

A measurement system is an appraisal activity whose primary purpose is to compare the product/service to applicable specifications and standards to determine whether it conforms to requirements.

A measurement method is VALID if it appropriately represents the feature of the measured object or phenomenon that is of interest.

A measurement is PRECISE if it produces small variation in repeated measurements of the same object.

A measurement system is ACCURATE (unbiased) if, on average it produces the true values of quantities of interest.

Factors in selecting equipment and systems for measurement and scoring:

- Repeatability – its ability to produce the same result over and over under the same conditions.
- Reproducibility – its ability to produce the same result at different places and at different times, e.g. under different conditions.

- Resolution (Sensitivity) – the smallest unit of scale that is produced.
- Magnification – amplification of output for measuring input. The higher the sensitivity, the greater the magnification required.
- Stability (drift) – the results, for the same conceptual samples, are the same over time.
- Linearity – expresses the constancy of the ratio between the increase in the *gold standard* and the corresponding increase of the result.
- Calibration – is the relation between the *gold standard* and the measure provided by the equipment. Calibration occurs before a decision to use the measure and must cover the range of circumstances and *gold standard* variation in which the measure will be made.

Corollary

Data are the basis for drawing conclusions, it does not determine decisions. The same data forces different people to draw the same conclusion but they can make different decisions based on it.

A conclusion can be 'right' or 'wrong' but not 'good' or 'bad'. A decision can be 'good' or 'bad' but not 'right' or 'wrong' – There are no wrong decisions, only bad ones, there are no bad conclusions only wrong ones!

These tools focus on the measurements made on individual animals and on the samples taken from them. *"If measurements are used to guide decisions, then it follows logically that the more error there is in the measurements, the more error there will be in the decisions based on those measurements. The purpose of Measurement System Analysis is to **qualify a measurement system for use by quantifying its accuracy, precision, and stability**."*[13] They thus deal with ensuring the properties of the original data collected by an animal recording system are known and are within acceptable limits of tolerance.

The key elements of MSA are: firstly, on the relationship between the measures and the *gold standard,* with *accuracy* and *precision* being key characteristics as illustrated in Figure 3.

[13] https://www.moresteam.com/toolbox/measurement-system-analysis.cfm accessed 7th January 2015.

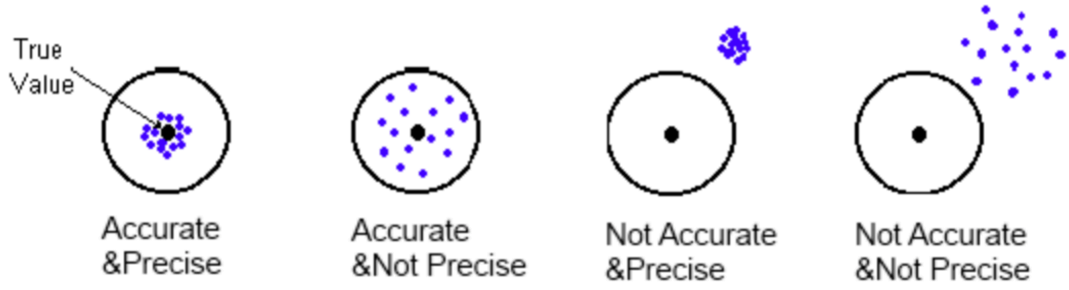

Figure 3. Measurement system analysis illustration showing the relationship between measure (blue spots) and gold standard (true value and central black spot) distinguishing accuracy (bias, systematic error, validity, trueness) from precision (reliability, random error).

Secondly, is the *stability* of the measure. *Stability* refers to the extent to which results of (conceptual) repeated measures on the same sample (or animal) give the same results. The main tools for measuring *stability* are *repeatability* and *reproducibility*. Where *repeatability* applies to repeated measures under the same condition and *reproducibility* applies to repeated measure under different conditions. What constitutes the same and different conditions needs to be carefully defined where these tools are being used. For animal recording this is particularly relevant as the same measures are being used in many organisations, spread over many countries, over extended periods of time.

MSA tools are used extensively in milk testing laboratories that provide milk composition measures for animal recording.

MSA tools are also particularly relevant for milk sampling and milk metering devices used in animal recording. Milk sampling is part of the process of determining milk composition and should be included in the consideration of milk composition measures using MSA tools. Milk metering is primarily concerned with determining the volume (or weight) of milk produced and MSA tools are also appropriate. In all of these cases there are well-established *gold standards* and both the standard and measure are on a continuous scale.

Animal recording includes situations where there is no precise *gold standard* or the measures are categorical with two or more categories. Examples include: calving ease (no *gold standard* and categorical), temperament (no *gold standard* and categorical), and linear traits (there is a *gold standard* at least by consensus or by an expert, and multiple categories). In these cases MSA is less applicable and other tools are more relevant depending on the uses made of the resulting data. Animal geneticists make extensive use of variance component analysis and linear models as tools for establishing the contribution of measurement and other non-genetic errors in such measures[14] [15]. They are able to evaluate

[14] K. Meyer and E.B. Burnside in 1987 JDS Volume 70, Issue 5, Pages 1061–1068. Scope for a Subjective Assessment of Milking Speed

alternative measures, for example, measures from a milking robot and scores from a linear scorer[16], and fat % from a single milking in a milking robot and a 24-hour conventional sample[17]. These tools are very robust and are also used extensively where the measure, or the underlying *gold standard,* are binomial or categorical. Validation for these measures is possible using selection experiments and studies of offspring of measured animals.

Animal recording for animal health purposes involves extensive testing for the presence or absence of a wide range of infectious agents. In these cases the *gold standard* is known and binary and the measure is also binary. The tools available include the extensive set provided by OIE as referenced in appendix 1.

Recording Process Optimization

In this section we describe a set of tools that can be used to address questions of accuracy in the context of the overall animal recording business.

The tools available for process optimisation, quality assurance and continuous improvement are extensive and well described[18]. These generic tools focus on continuous improvement in a business producing products and services. They do not contain examples specific to animal recording. They are described in an IBM™ publication for which the executive summary states:

Business process management (BPM) technologies and service-oriented architectures (SOAs) combine with Lean and Six Sigma™ to accelerate improvements and results. At the same time, they increase organizational agility and technology-enabled responsiveness. Early adopters who have worked their way past cultural and organizational barriers are seeing impressive performance and financial results such as the following examples:

a. *Improved responsiveness to market challenges, opportunities, and changes in regulatory requirements through more tightly coupled yet more flexible business and technical architectures*

b. *Improved ability to innovate and achieve strategic differentiation by driving change into the market and tuning processes to meet the specific needs of key market and customer segments*

[15] D. P. Berry, J. Coyne, B. Coughlan, M. Burke, J. McCarthy, B. Enright, A. R. Cromie and S. McParland. Animal (2013), 7:11, pp 1750–1758. The Animal Consortium 2013 doi:10.1017/S1751731113001511. Genetics of milking characteristics in dairy cows.

[16] K. Byskov, L.H. Buch and G.P. Aamand. INTERBULL BULLETIN NO. 46. Cork, Ireland, May 28 - 31, 2012. Possibilities of Implementing Measures from Automatic Milking Systems in Routine Evaluations of Udder Conformation and Milking Speed.

[17] R. Peeters and P. J. B. Galesloot. J. Dairy Sci. 85:682–688, American Dairy Science Association, 2002. Estimating Daily Fat Yield from a Single Milking on Test Day for Herds with a Robotic Milking System.

[18] Applying Lean, Six Sigma, BPM, and SOA to Drive Business Results. Hans Skalle and Bill Hahn. This document, REDP-4447-01, was created or updated on April 18, 2013. IBM Redbooks. http://www.redbooks.ibm.com/abstracts/redp4447.html?Open. Accessed 7th Jan 2014.

c. *Reduced process costs through automation and an improved ability to monitor, detect, and respond to problems and events by using real-time data, automated alerts, and planned escalation*

d. *Lower technical implementation costs through shared services and higher levels of component reuse; changing and improving processes becomes easier and more cost effective*

e. *Lower analysis costs through collaborative online process modeling tools, access to real-time process data, and advanced process simulation capabilities.*

The term *Lean* is much heralded but often misunderstood. Its origins are from Toyota's Production System (TPS)[19] in the early 1980s. At the core of the TPS was Toyota's relentless drive to reduce waste and improve quality in their supply chain and manufacturing sites. *Lean* simply focuses your team on the elimination of waste so that every step in the process adds value in the eyes of the customer.

As a result of the success in Toyota, *Lean* management techniques and principles became widely used throughout the manufacturing world. Whether you are in the manufacturing or service industry every business activity or operation can be process mapped.

The term *Six Sigma™* is derived from the study of *process capability*. It is a measure of the *spread* and *variance* in your process. Processes that operate within *Six Sigma™* quality are assumed to produce long-term defect levels below 3.4 defects per million opportunities. *Six Sigma™* is a registered trademark of Motorola. Inc[20]. At the core of all *Six Sigma™* projects lies Deming's PDSA (Plan, Do, Study, Act) cycle of continuous improvement. However in Motorola' *Six Sigma*™ methodology, the principle is expanded into a five step discipline of DMAIC (Define, Measure, Analyse, Improve and Control – refer to Figure 4.

[19] A study of the Toyota Production System, Shigeo Shingo, Productivity Press, 1989.

[20] "The Inventors of Six Sigma": Motorola website archive https://web.archive.org/web/20051106025733/http://www.motorola.com/content/0,,3079,00.html.

Figure 4. DMAIC explained.

Six Sigma™ toolkit offers a range of analysis techniques that can be used to improve your measurement system and service operation:

- Statistical Process Control (SPC) charts, Process/Machine Capability
- Gauge R & R (Repeatability and Reproducibility), aka Measurement System Analysis (MSA), Analysis of Variance (ANOVA).
- Design of Experiments
- 5S – workplace re-organisation
- FMEA – Failure Mode & Effect Analysis
- Fishbone/ Ishikawa Diagrams (5 whys and other diagrams designed to analyse data)
- Balanced Business Scorecards for KPI s

This is by no means an exhaustive list but real life examples of tools used in operational improvement programmes.

While *Six Sigma*™ alone will undoubtedly improve your QUALITY by getting your processes under control, it will not impact significantly on SPEED of processing or FLEXIBILITY – both are very necessary survival traits in today's business world! By combining and incorporating *Lean* with *Six Sigma*™ methodologies and tools, (refer to Table 4), we can sustain all three; Improved QUALITY, Improved EFFICIENCY and Improved FLEXIBILITY.

Table 4. The tools of Six Sigma™ (DMAIC) and Lean.

Six Sigma™ (DMAIC)	Lean
Define requirements	Define value to Customer
Map and measure the process	Value Stream Map Core Processes – challenge waste
Analyse the causes	Create Flow with value-creating steps only
Improve the process	Pull – design flow around customers pull signals not push
Control to sustain consistent KPI's	Perfection – always strive to further reduce, iterate

Six Sigma™ is an analytical approach to performance improvement and when used with *Lean* management techniques, it is a powerful tool for improving the performance of your business. It is about harnessing the people resource in your company to forensically breakdown and reconstruct your key processes to determine if they are set up for maximum efficiency. By combining the hard tools of *Six Sigma*™ and the optimisation tools of *Lean*, you can develop simple, customer-focused process maps with your staff to develop a leaner, more efficient process.

These tools address the three key elements being considered in this report: cost, benefit and accuracy.

Cost Benefits – Case Study 1

One of us[21] has described a tool that provides a generic solution to optimising the design of an animal recording system for a single purpose. It evaluates the relationship between the costs and benefits of animal recording and contains two examples which addresses two questions:

a. Implementation of a new technique should increase accuracy. Can this increase be economically justified?

b. Implementation of a new technique should reduce costs at the expense of reduced accuracy. Can the reduction in accuracy be economically justified?

Cost Benefits – Case Study 2

This[22] tool provides a more rigorous approach to making decisions regarding the use of information products claimed to enhance animal production. Two examples are given.

[21] Economic Evaluation of Accuracy. J. I. Weller, ARO, The Volcani Center. 3 page mimeo. Draft December 2014.

[22] Application of Type I and II Errors in Dairy Farm Management Decision Making. David. Galligan, William Chalupa, and Charles F. Ramberg, Jr. 1991 J Dairy Sci 74:902-910.

Example 1:

An example of quantifying the financial loss due to poor data accuracy in making culling decisions for individual dairy cows:

Culling decisions should be made based on ranking cows for future profitability. The lowest ranked animals should be culled first. This requires cashflow predictions for each cow into the future. Various research groups have computer programs that do this. Data accuracy affects these cashflow predictions. For example, if we underestimate fat% for a cow, she may be ranked lower and get culled (type I error – false negative). Another cow that should be culled stays in the herd (type II – false positive) a little longer. The economic losses of these decision errors could be quantified with computer simulation.

Example 2:

Another example is at the farm level:

Say we want to detect a problem in reproduction as soon as possible. For example we monitor days open, or pregnancy rate, or conception rate etc. There is random chance, so it is not immediately clear if there is a problem or not. Investigation of a possible problem costs time and money. It is a false alarm, money and time are wasted (type I). Not fixing a real problem also costs money (type II). So the question is, when should the management system signal a possible problem?

Statistical process control charts balance the type I and type II decision errors and minimize the total loss. Simulation could provide insight in these costs.

One could then insert less accurate data. Now there are more false alarms and maybe the type II errors also change. So there is a new total loss. This new total loss is greater than when accuracy of data is good.

Statistical process control charts can help with this.

Appendix 1 to Report of ICAR Accuracy Task Force

Terminology relevant to ICAR Activities – from VIM and ISO

The below definitions were extracted from the VIM (International Vocabulary of Metrology)[1], thereby keeping their original ordering and number and including the relevant notes with each definition. Where appropriate, also the definitions according to ISO 5725-1:1994[2] are listed in *blue italics*.

2 Measurement terms

2.3 measurand

quantity intended to be measured

NOTE 1 The specification of a measurand requires knowledge of the kind of quantity, description of the state of the phenomenon, body, or substance carrying the quantity, including any relevant component, and the chemical entities involved.

NOTE 4 In chemistry, "analyte", or the name of a substance or compound, are terms sometimes used for 'measurand'. This usage is erroneous because these terms do not refer to quantities.

2.6 measurement procedure

detailed description of a measurement according to one or more measurement principles and to a given measurement method, based on a measurement model and including any calculation to obtain a measurement result

2.7 reference measurement procedure

measurement procedure accepted as providing measurement results fit for their intended use in assessing measurement trueness of measured quantity values obtained from other measurement procedures for quantities of the same kind, in calibration, or in characterizing reference materials

2.9 measurement result

result of measurement

set of quantity values being attributed to a measurand together with any other available relevant information

NOTE 2 A measurement result is generally expressed as a single measured quantity value and a measurement uncertainty. If the measurement uncertainty is considered to be negligible for some purpose, the measurement result may be expressed as a single measured quantity value. In many fields, this is the common way of expressing a measurement result.

2.11 true quantity value

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[1] Joint Committee for Guides in Metrology. International vocabulary of metrology – Basic and general concepts and associated terms (VIM) 3rd edition 2012.

[2] International Organization for Standardization. ISO 5725-1:1994. Accuracy (trueness and precision) of measurement methods and results – Part 1: General principles and definitions

true value of a quantity,

true value quantity value consistent with the definition of a quantity

NOTE 1 In the Error Approach to describing measurement, a true quantity value is considered unique and, in practice, unknowable. The Uncertainty Approach is to recognize that, owing to the inherently incomplete amount of detail in the definition of a quantity, there is not a single true quantity value but rather a set of true quantity values consistent with the definition. However, this set of values is, in principle and in practice, unknowable. Other approaches dispense altogether with the concept of true quantity value and rely on the concept of metrological compatibility of measurement results for assessing their validity.

NOTE 2 In the special case of a fundamental constant, the quantity is considered to have a single true quantity value.

NOTE 3 When the definitional uncertainty associated with the measurand is considered to be negligible compared to the other components of the measurement uncertainty, the measurand may be considered to have an "essentially unique" true quantity value. This is the approach taken by the GUM and associated documents, where the word "true" is considered to be redundant.

2.13 measurement accuracy

accuracy of measurement,

accuracy

closeness of agreement between a measured quantity value and a true quantity value of a measurand

NOTE 1 The concept 'measurement accuracy' is not a quantity and is not given a numerical quantity value. A measurement is said to be more accurate when it offers a smaller measurement error.

NOTE 2 The term "measurement accuracy" should not be used for measurement trueness and the term "measurement precision" should not be used for 'measurement accuracy', which, however, is related to both these concepts.

NOTE 3 'Measurement accuracy' is sometimes understood as closeness of agreement between measured quantity values that are being attributed to the measurand.

ISO 5725-1: the closeness of agreement between a test result and the accepted reference value

2.14 measurement trueness

trueness of measurement,

trueness

closeness of agreement between the average of an infinite number of replicate measured quantity values and a reference quantity value

NOTE 1 Measurement trueness is not a quantity and thus cannot be expressed numerically, but measures for closeness of agreement are given in ISO 5725.

NOTE 2 Measurement trueness is inversely related to systematic measurement error, but is not related to random measurement error.

NOTE 3 “Measurement accuracy” should not be used for ‘measurement trueness’.

ISO 5725-1: the closeness of agreement between the average value obtained from a large series of test results and an accepted reference value

2.15 measurement precision

precision

closeness of agreement between indications or measured quantity values obtained by replicate

measurements on the same or similar objects under specified conditions

NOTE 1 Measurement precision is usually expressed numerically by measures of imprecision, such as standard deviation, variance, or coefficient of variation under the specified conditions of measurement.

NOTE 2 The ‘specified conditions’ can be, for example, repeatability conditions of measurement, intermediate precision conditions of measurement, or reproducibility conditions of measurement (see ISO 5725-1:1994).

NOTE 3 Measurement precision is used to define measurement repeatability, intermediate measurement precision, and measurement reproducibility.

NOTE 4 Sometimes “measurement precision” is erroneously used to mean measurement accuracy.

ISO 5725-1: the closeness of agreement between independent test results obtained under stipulated conditions
NOTE: Precision depends only on the distribution of random errors and does not relate to the true value or the specified value

2.16 measurement error

error of measurement, error

measured quantity value minus a reference quantity value

NOTE 1 The concept of ‘measurement error’ can be used both

a) when there is a single reference quantity value to refer to, which occurs if a calibration is made by means of a measurement standard with a measured quantity value having a negligible measurement uncertainty or if a conventional quantity value is given, in which case the measurement error is known, and

b) if a measurand is supposed to be represented by a unique true quantity value or a set of true quantity values of negligible range, in which case the measurement error is not known.

NOTE 2 Measurement error should not be confused with production error or mistake.

2.17 systematic measurement error

systematic error of measurement, systematic error

component of measurement error that in replicate measurements remains constant or varies in a predictable manner

NOTE 1 A reference quantity value for a systematic measurement error is a true quantity value, or a measured quantity value of a measurement standard of negligible measurement uncertainty, or a conventional quantity value.

NOTE 2 Systematic measurement error, and its causes, can be known or unknown. A correction can be applied to compensate for a known systematic measurement error.

NOTE 3 Systematic measurement error equals measurement error minus random measurement error.

2.18 measurement bias

bias

estimate of a systematic measurement error

ISO 5725-1: the difference between the expectation of the test results and an accepted reference value
NOTE: Bias is the total systematic error as contrasted to random error. There may be one or more systematic error components contributing to the bias.

2.19 random measurement error

random error of measurement, random error

component of measurement error that in replicate measurements varies in an unpredictable manner

NOTE 1 A reference quantity value for a random measurement error is the average that would ensue from an infinite number of replicate measurements of the same measurand.

NOTE 2 Random measurement errors of a set of replicate measurements form a distribution that can be summarized by its expectation, which is generally assumed to be zero, and its variance.

NOTE 3 Random measurement error equals measurement error minus systematic measurement error.

2.20 repeatability condition of measurement

repeatability condition

condition of measurement, out of a set of conditions that includes the same measurement procedure, same operators, same measuring system, same operating conditions and same location, and replicate measurements on the same or similar objects over a short period of time

NOTE 1 A condition of measurement is a repeatability condition only with respect to a specified set of repeatability conditions.

NOTE 2 In chemistry, the term "intra-serial precision condition of measurement" is sometimes used to designate this concept.

ISO 5725-1: Conditions where independent test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment within short intervals of time

2.21 measurement repeatability

repeatability

measurement precision under a set of repeatability conditions of measurement

ISO 5725-1: precision under repeatability conditions

*ISO 5725-1: **Repeatability standard deviation**: The standard deviation of test results obtained under repeatability conditions*

*ISO 5725-1: **Repeatability limit**: The value less than or equal to which the absolute difference between two test results obtained under repeatability conditions may be expected to be with a probability of 95%*

2.24 reproducibility condition of measurement

reproducibility condition

condition of measurement, out of a set of conditions that includes different locations, operators, measuring systems, and replicate measurements on the same or similar objects

NOTE 1 The different measuring systems may use different measurement procedures.

NOTE 2 A specification should give the conditions changed and unchanged, to the extent practical.

ISO 5725-1: Conditions where independent test results are obtained with the same method on identical test items in different laboratories with different operators using different equipment

2.25 measurement reproducibility

reproducibility

measurement precision under reproducibility conditions of measurement

ISO 5725-1: precision under reproducibility conditions

*ISO 5725-1: **Reproducibility standard deviation**: The standard deviation of test results obtained under reproducibility conditions.*

*ISO 5725-1: **Reproducibility limit**: The value less than or equal to which the absolute difference between two test results obtained under reproducibility conditions may be expected to be with a probability of 95%.*

***outlier** (from ISO 5725-1, not defined in the VIM Vocabulary)*

a member of a set of values which is inconsistent with the other members of that set.

NOTE: ISO 5725-2 specifies the statistical tests and the significance level to be used to identify outliers in trueness and precision experiments.

2.26 measurement uncertainty

uncertainty of measurement, uncertainty

non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used

NOTE 1 Measurement uncertainty includes components arising from systematic effects, such as components associated with corrections and the assigned quantity values of measurement standards, as well as the definitional uncertainty. Sometimes estimated systematic effects are not corrected for but, instead, associated measurement uncertainty components are incorporated.

NOTE 2 The parameter may be, for example, a standard deviation called standard measurement uncertainty (or a specified multiple of it), or the half-width of an interval, having a stated coverage probability.

NOTE 3 Measurement uncertainty comprises, in general, many components. Some of these may be evaluated by Type A evaluation of measurement uncertainty from the statistical distribution of the quantity values from series of measurements and can be characterized by standard deviations. The other components, which may be evaluated by Type B evaluation of measurement uncertainty, can also be characterized by standard deviations, evaluated from probability density functions based on experience or other information.

NOTE 4 In general, for a given set of information, it is understood that the measurement uncertainty is associated with a stated quantity value attributed to the measurand. A modification of this value results in a modification of the associated uncertainty.

2.30 standard measurement uncertainty

standard uncertainty of measurement, standard uncertainty

measurement uncertainty expressed as a standard deviation

2.39 calibration

operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication

NOTE 1 A calibration may be expressed by a statement, calibration function, calibration diagram, calibration curve, or calibration table. In some cases, it may consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.

NOTE 2 Calibration should not be confused with adjustment of a measuring system, often mistakenly called “self-calibration”, nor with verification of calibration.

2.41 metrological traceability

property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty

NOTE 1 For this definition, a ‘reference’ can be a definition of a measurement unit through its practical realization, or a measurement procedure including the measurement unit for a non-ordinal quantity, or a measurement standard.

NOTE 2 Metrological traceability requires an established calibration hierarchy.

NOTE 5 Metrological traceability of a measurement result does not ensure that the measurement uncertainty is adequate for a given purpose or that there is an absence of mistakes.

NOTE 6 A comparison between two measurement standards may be viewed as a calibration if the comparison is used to check and, if necessary, correct the quantity value and measurement uncertainty attributed to one of the measurement standards.

NOTE 8 The abbreviated term "traceability" is sometimes used to mean 'metrological traceability' as well as other concepts, such as 'sample traceability' or 'document traceability' or 'instrument traceability' or 'material traceability', where the history ("trace") of an item is meant. Therefore, the full term of "metrological traceability" is preferred if there is any risk of confusion.

2.45 validation

verification, where the specified requirements are adequate for an intended use

EXAMPLE A measurement procedure, ordinarily used for the measurement of mass concentration of nitrogen in water, may be validated also for measurement of mass concentration of nitrogen in human serum.

4 Properties of measuring devices

4.7 measuring interval

working interval

set of values of quantities of the same kind that can be measured by a given measuring instrument or measuring system with specified instrumental measurement uncertainty, under defined conditions

NOTE 1 In some fields, the term is "measuring range" or "measurement range".

NOTE 2 The lower limit of a measuring interval should not be confused with detection limit.

4.18 detection limit

limit of detection

measured quantity value, obtained by a given measurement procedure, for which the probability of falsely claiming the absence of a component in a material is *ß*, given a probability *α* of falsely claiming its presence

NOTE 1 IUPAC recommends default values for *ß* and *α* equal to 0.05.

NOTE 2 The abbreviation LOD is sometimes used.

NOTE 3 The term "sensitivity" is discouraged for 'detection limit'.

4.31 calibration curve

expression of the relation between indication and corresponding measured quantity value

NOTE A calibration curve expresses a one-to-one relation that does not supply a measurement result as it bears no information about the measurement uncertainty.

5 Measurement standards

5.1 measurement standard

etalon

realization of the definition of a given quantity, with stated quantity value and associated measurement uncertainty, used as a reference

EXAMPLE 1 kg mass measurement standard with an associated standard measurement uncertainty of 3 μg.

NOTE 1 A "realization of the definition of a given quantity" can be provided by a measuring system, a material measure, or a reference material.

NOTE 2 A measurement standard is frequently used as a reference in establishing measured quantity values and associated measurement uncertainties for other quantities of the same kind, thereby establishing metrological traceability through calibration of other measurement standards, measuring instruments, or measuring systems.

NOTE 3 The term "realization" is used here in the most general meaning. It denotes three procedures of "realization". The first one consists in the physical realization of the measurement unit from its definition and its realization sensu stricto. The second, termed "reproduction", consists not in realizing the measurement unit from its definition but in setting up a highly reproducible measurement standard based on a physical phenomenon, as it happens, e.g. in case of use of frequency-stabilized lasers to establish a measurement standard for the metre, of the Josephson effect for the volt or of the quantum Hall effect for the ohm. The third procedure consists in adopting a material measure as a measurement standard. It occurs in the case of the measurement standard of 1 kg.

NOTE 4 A standard measurement uncertainty associated with a measurement standard is always a component of the combined standard measurement uncertainty(see GUM:1995, 2.3.4) in a measurement result obtained using the measurement standard. Frequently, this component is small compared with other components of the combined standard measurement uncertainty.

NOTE 5 Quantity value and measurement uncertainty must be determined at the time when the measurement standard is used.

NOTE 6 Several quantities of the same kind or of different kinds may be realized in one device which is commonly also called a measurement standard.

NOTE 7 The word "embodiment" is sometimes used in the English language instead of "realization".

NOTE 8 In science and technology, the English word "standard" is used with at least two different meanings: as a specification, technical recommendation, or similar normative document (in French "norme") and as a measurement standard (in French "étalon"). This Vocabulary is concerned solely with the second meaning.

NOTE 9 The term "measurement standard" is sometimes used to denote other metrological tools, e.g. 'software measurement standard' (see ISO 5436-2).

5.13 reference material

RM

material, sufficiently homogeneous and stable with reference to specified properties, which has been established to be fit for its intended use in measurement or in examination of nominal properties

NOTE 1 Examination of a nominal property provides a nominal property value and associated uncertainty. This uncertainty is not a measurement uncertainty.

NOTE 2 Reference materials with or without assigned quantity values can be used for measurement precision control whereas only reference materials with assigned quantity values can be used for calibration or measurement trueness control.

NOTE 3 'Reference material' comprises materials embodying quantities as well as nominal properties.

EXAMPLE 1 fish tissue containing a stated mass fraction of a dioxin, used as a calibrator.

EXAMPLE 2 colour chart indicating one or more specified colours;

NOTE 4 A reference material is sometimes incorporated into a specially fabricated device.

EXAMPLE 1 Glass of known optical density in a transmission filter holder.

NOTE 5 Some reference materials have assigned quantity values that are metrologically traceable to a measurement unit outside a system of units. Such materials include vaccines to which International Units (IU) have been assigned by the World Health Organization.

NOTE 6 In a given measurement, a given reference material can only be used for either calibration or quality assurance.

NOTE 7 The specifications of a reference material should include its material traceability, indicating its origin and processing.

5.14 certified reference material

CRM

reference material, accompanied by documentation issued by an authoritative body and

providing one or more specified property values with associated uncertainties and traceabilities, using valid procedures

5.18 reference quantity value

reference value

quantity value used as a basis for comparison with values of quantities of the same kind

NOTE 1 A reference quantity value can be a true quantity value of a measurand, in which case it is unknown, or a conventional quantity value, in which case it is known.

NOTE 2 A reference quantity value with associated measurement uncertainty is usually provided with reference to

a) a material, e.g. a certified reference material,

b) a device, e.g. a stabilized laser,

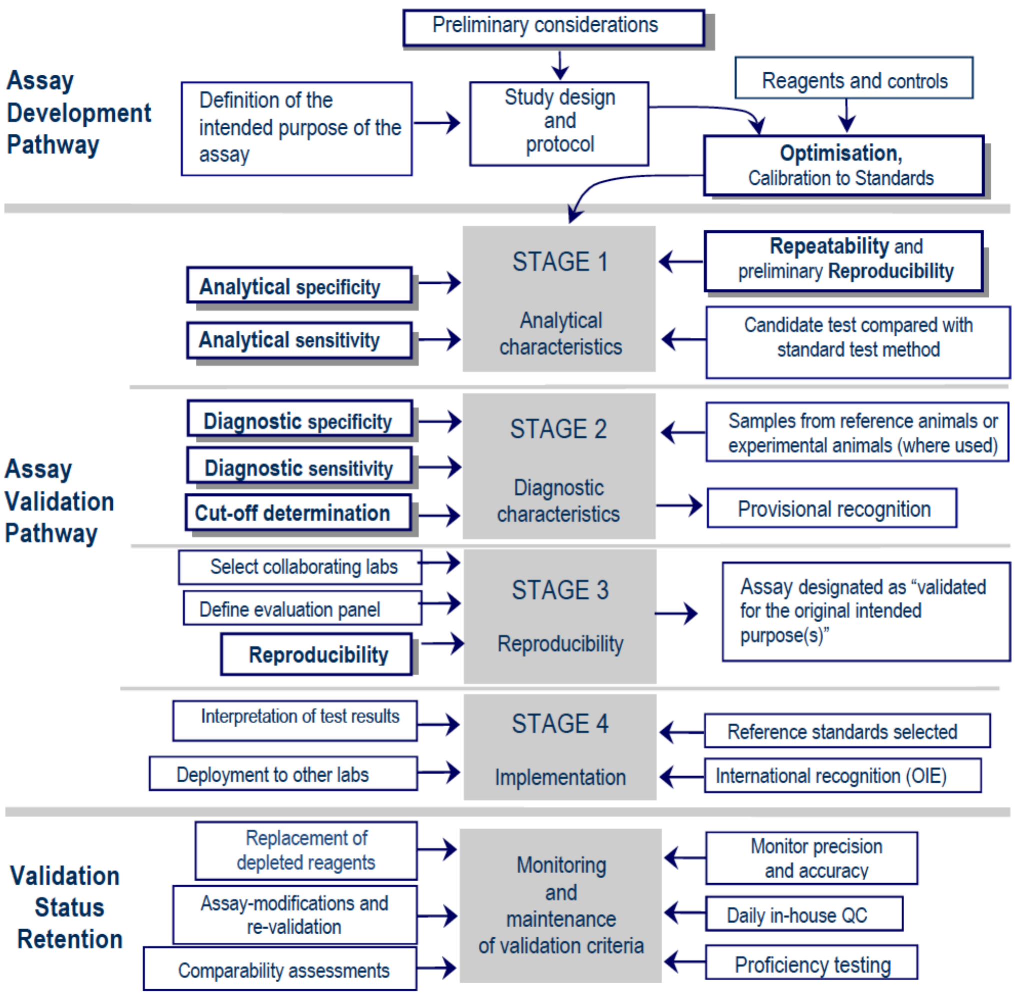
c) a reference measurement procedure,

d) a comparison of measurement standards.

Disease Testing Terminology

The OIE[3] Terrestrial Manual Glossary contains a figure particular relevance to our work and this repeated as Figure 1. It deals with assay development and validation for infectious diseases extracted from the Terrestrial Manual (page 4 Chapter 1.1.5).

Figure 1. The assay development and validation pathways with assay validation criteria highlighted in bold typescript within shadowed boxes.



Reference: Macintosh HD:Users:bww:Data:Wickham Ltd:Customers:ICAR:ICAR SC WG TF:Groups:Task Forces:Accuracy:Appendix 1 Terminology.docx

[3] World Organisation for Animal Health – www.oie.int.