Measurement System Management

Harvey T.Dearden
Consultant
Time Domain Solutions Ltd
Llandudno
Conwy
LL30 1NZ
UK

Peter A.Barlow
Services Manager
Endress+Hauser Ltd
Floats Road
Manchester
M23 9NF
UK

Abstract – Discussion of the role of measurement system calibration in fulfilling wider business objectives, together with a description of a mathematical approach to determination of optimal calibration intervals using both a classical linear drift model and also a random stepwise shift model. Also discusses refinements in approach to development and nomination of calibration procedures.

Index Terms – Measurement calibration, Optimisation, Drift models, Calibration procedures

INTRODUCTION

In the context of the process industries, calibration of measurement systems is performed for two fundamental reasons:

- To correct drift which would otherwise reduce the accuracy of the measurement
- To give a level of assurance that a measurement is maintained within appropriate tolerances.

These concerns underpin many regulatory or good practice stipulations in different industry applications, for example:

- Health & Safety - Protection systems, alarms & trips
- Product Quality - Quality assurance provisions, system/process validation
- Custody Transfer - Contractual requirements
- Fiscal - Government tax/duty regulations
- Environmental – Compliance monitoring

With all the technological concerns it is understandable that the business concerns are sometimes overlooked. Yet calibration is not intrinsically a good thing, it is a means to an end; the reduction of the potential costs associated with error or providing confidence in a measurement.

If the cost of the calibration activity is greater than the associated business gain, the calibration is actually damaging the business. At first it seems an extraordinary thought that calibration could be a bad thing, but it is important to keep the business context in mind. It is possible that a lot of calibration effort is misplaced and does not effectively contribute to business objectives.

An effective calibration regime will minimise business costs and maximise revenue. Too much or too little calibration will reduce profit.

NOMINATION OF CALIBRATION INTERVAL

We may identify the optimal calibration interval from consideration of the total cost to a business of calibration activity and the measurement drift it corrects. Drift (*D%*) is classically modelled as a linear function of time:

$$D = k.t \qquad (1)$$

Where:

k is %drift per unit time
t is time elapsed since calibration

with calibration period T (years), average drift is

$$D_{avg} = \frac{1}{2}.k.\mathrm{T} \qquad (2)$$

We may assign annual cost to the business as a linear function of drift and production throughput (P units/yr), with a cost assigned to unit percentage drift per production unit (C_d):

Annual Cost of Drift = average drift x annual throughput x cost per unit %drift per production unit.

$$C_{DA} = \frac{1}{2}.k.\mathrm{T}.P.C_d \qquad (3)$$

[We assume for our purpose here that calibration reduces error to zero. Although a systematic error may remain after calibration, in terms of the relationship between calibration interval and business costs, this may be disregarded.]

When a measurement is not related to throughput (e.g. pressure, temperature), the annual cost may determined directly from evaluation of the cost implication of an error in a measurement.

Cost of calibration may be notionally assigned per occasion (C_C), and the annualised cost C_{CA} may be determined as a function of the reciprocal of calibration period.

$$C_{CA} = C_C / \mathrm{T} \qquad (4)$$

We can combine these to determine the total business cost as a function of calibration period

Total Annual Cost:

$$C_A = \frac{C_C}{T} + \frac{1}{2}.k.TPC_d \qquad (5)$$

Differentiating with respect to Period T, we have:

$$\frac{\partial C_A}{\partial T} = -\frac{C_C}{T^2} + \frac{1}{2}kPC_d \qquad (6)$$

So we have a minimum when:

$$T = \sqrt{\frac{2.C_C}{kPC_d}} \qquad (7)$$

As an example of this evaluation method, consider the calibration of tanker loading gantry meters. From a study of a population of over 400 meters on a variety of petrol/kerosene/diesel duties, and a total of 890 calibrations, a distribution as shown in Fig. 1 was identified. (Samples outside -0.3 and +0.3 are lumped.)

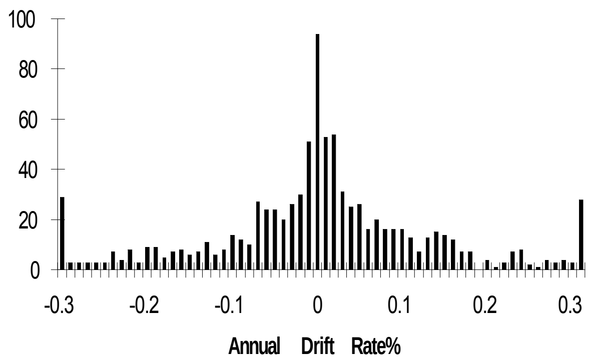

Fig.1 Frequency Distribution Plot

Average <u>positive</u> drift rate (from 416 calibrations revealing product giveaway) was established as 0.09% per year. If we take the cost of 1% drift as nominally €0.35 per litre, and nominal throughput as 250 x 10^6 litres per year, with nominal cost per calibration of €300 (assuming €150 per meter, but only half the meter population suffering a positive shift), the corresponding optimum period is 1 month. The optimum is relatively broad, so we do not claim that the selection of calibration period needs to be fine tuned on the basis of this evaluation approach, but it does provide a simple quantitative basis for evaluating calibration period nomination.

Although drift is classically modelled as a linear function of time, it may be that a sudden shift in calibration occurs, perhaps due to some incident; a physical blow or some environmental or process excursion perhaps, or the sudden degradation of some component. If this event causes a gross shift in calibration, this will become immediately apparent to the user, and corrective measures may be taken.

It is possible however that the shift is below a value where the error is revealed to the user; the error could then persist until the next calibration. To evaluate the risk to the business, it is possible to assign a frequency to these random type occurrences and evaluate the corresponding probability of incurring a business loss beyond an associated threshold.

Given:

C_{A1}	Annual Cost of 1% error (€)
MTBS	Mean Time Between Unrevealed Shifts of Magnitude *S* (Years)
S	Shift (%)
T	Calibration Period (years)
L	Potential Loss (€)

The loss arising from a shift that arises before half the calibration period has elapsed is:

$$L > C_{A1} \times S \times 100 \times T \times 0.5 \qquad (8)$$

Probability (P_r) of incurring such loss in a given calibration interval (i.e. the probability of the shift occurring before half the period has elapsed):

$$P_r = 0.5 \times T / MTBS \qquad (9)$$

Clearly there is some difficulty in establishing values for S and MTBS, but nevertheless, this approach allows an exploration of business risk on a consistent basis.

If we take the previous example and use a figure for S of +0.3%, with MTBS of 10 years (28 events in approximately 300 meter-years, we can calculate a probability (within each calibration interval of 0.33 yrs) of 1.7% of a loss greater than €43,000. Equivalent to approximately 5% chance per meter-year of such loss being exceeded.

For most duties with modern solid state instrumentation, we do not find that this consideration is likely to prompt a calibration period shorter than that suggested by the linear drift model.

In the oil & gas sector the benefits of proper management of measurement systems is generally well understood because of the requirements of fiscal flow measurement systems, and calibration routines are often exploited as a diagnostic tool. The validation requirements within the pharmaceutical sector have driven a wider appreciation there. However there is perhaps scope to further propagate these methods into other industry sectors and to other areas within any given sector, with commercial advantage to the related businesses.

MOBILE PROVING RIGS

The advent of the Coriolis mass meter has allowed the development of a new generation of mobile proving rigs which have facilitated the development of similar services to other process industry sectors and to other flow measurement duties.

The Coriolis meter is well suited to this function in that it offers high stability, high accuracy and is insensitive to flow disturbances. It also offers a direct measure of mass (as well as auxiliary measurements of density, temperature and derived measurement of volume) and offers a direct measure of instantaneous flow rate as well as allowing integration for total mass/volume.

In-situ calibration of flow meters offers a number of advantages:

- It is potentially less disruptive to process operations than arranging removal and despatch of the meter under test.
- The calibration corrects for any installation specific influences, such as up and downstream piping configurations, line condition and alignment, presence of fittings etc.
- It avoids potential errors with incorrect set up during remote calibration or on return to service.
- The calibration may correct for environmental influences such as ambient temperature and seasonal variations.

PROCEDURE DEVELOPMENT PROCESS MODELS

Calibration methods and intervals are often wrongly assigned through the application of inappropriate process models. This usually results in unnecessary expense.

The need to calibrate/verify equipment periodically is a critical activity in a quality controlled operation. However, many companies operating a QA system effectively end up 'going through the motions' simply to satisfy external audit requirements rather than addressing the true business requirements.

Typically their measurement verification procedures will:

- Be applied to many measurements which make no contribution to quality. For example, if you consider the common cascade control configuration, it is apparent that any drift in the secondary (slave) loop set point, measurement or output, will be corrected by the action of the primary controller. Routine calibration of secondary loop systems is therefore usually redundant.
- Use an arbitrary calibration interval (typically 1 year), without proper technical justification.
- Use calibration specifications tied to the instrument manufacturer's performance specifications rather than the quality requirements of the production process.
- Require full calibration on every occasion, even though appropriate intermediate checks may be used to legitimately extend full calibration intervals.

This approach leads to unnecessary costs and disruption. A rational and prudent approach, using an intelligent process model, will allow both costs and disruption to be minimised whilst meeting all quality assurance verification requirements.

A. Inappropriate Process Models

Fig. 2 shows a typical process method adopted in the preparation of calibration manuals. Generic analysis is focussed on instrument types; the tag specific on individual duties. This looks plausible, but is superficial in its approach. Often this approach is adopted by default without consideration of whether it is properly aligned with the business requirements. Variations on this common theme will be found, but they rarely differ significantly in their essentials.

This model is often adopted implicitly without formal definition; nevertheless when the specified calibration requirements are critically examined they will usually be found to conform to this basic model.

Note in particular the following points:

- Calibration specification is determined by the instrument manufacturer's accuracy specification rather than the business need.
- Calibration Standard Operating Procedures (SOPs) are for full calibration, there are no provisions for intermediate checks.
- Calibration SOPs are written for instrument types rather than duties.
- Calibration intervals are based on defaults perceived as good practice rather than business need.

B. New Process Model

A more appropriate process model is outlined in Fig. 3 [This is complete in all essentials, but is not entirely rigorous in its representation of the details; such a diagram would be unwieldy and would tend to obscure the fundamentals of the philosophy.] Here the generic analysis is focussed on the combination of instrument type <u>and</u> duty.

This approach centres on the business requirement rather than instrument capability. In this respect the approach identifies the minimal cost approach. Overall cost is built from two components; the cost of calibration and the cost of measurement drift. Too elaborate or too frequent calibration will raise overheads, too simplistic or too infrequent calibration will raise the costs associated with compromised product quality or process plant yield/efficiency.

Note in particular the following points:

- Measurements are first considered to determine whether they are quality critical (in the widest sense).
- Measurement duty is factored into assignment of drift values, the cost of drift and the selection of SOP.
- Calibration intervals are individually assigned based on minimum overall business cost.
- Calibration SOPs are written for both full calibration and for intermediate checks.
- Cost of drift is determined for different drift models as appropriate; continuous linear drift and random stepwise shift.
- Multiple action thresholds are assigned to provide more intelligent discrimination in maintenance response

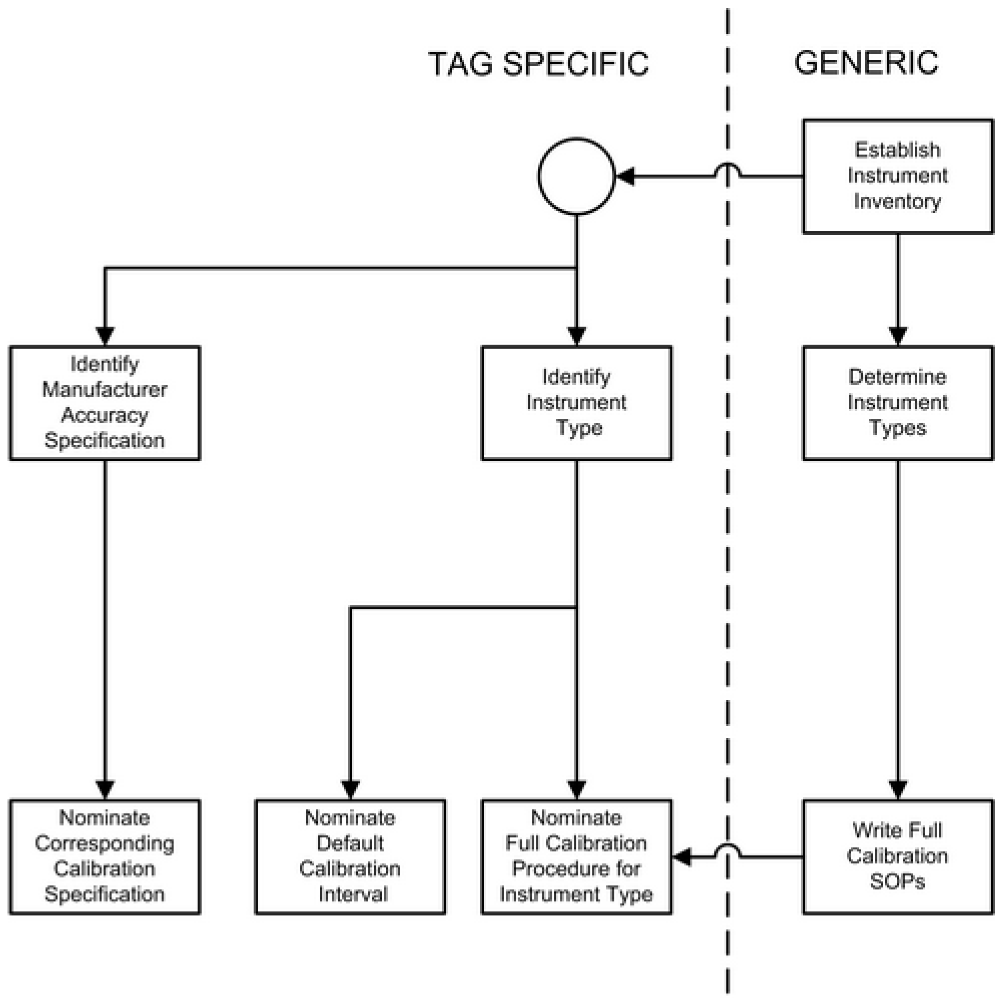

Fig.2 Simple Procedure Development Process Model

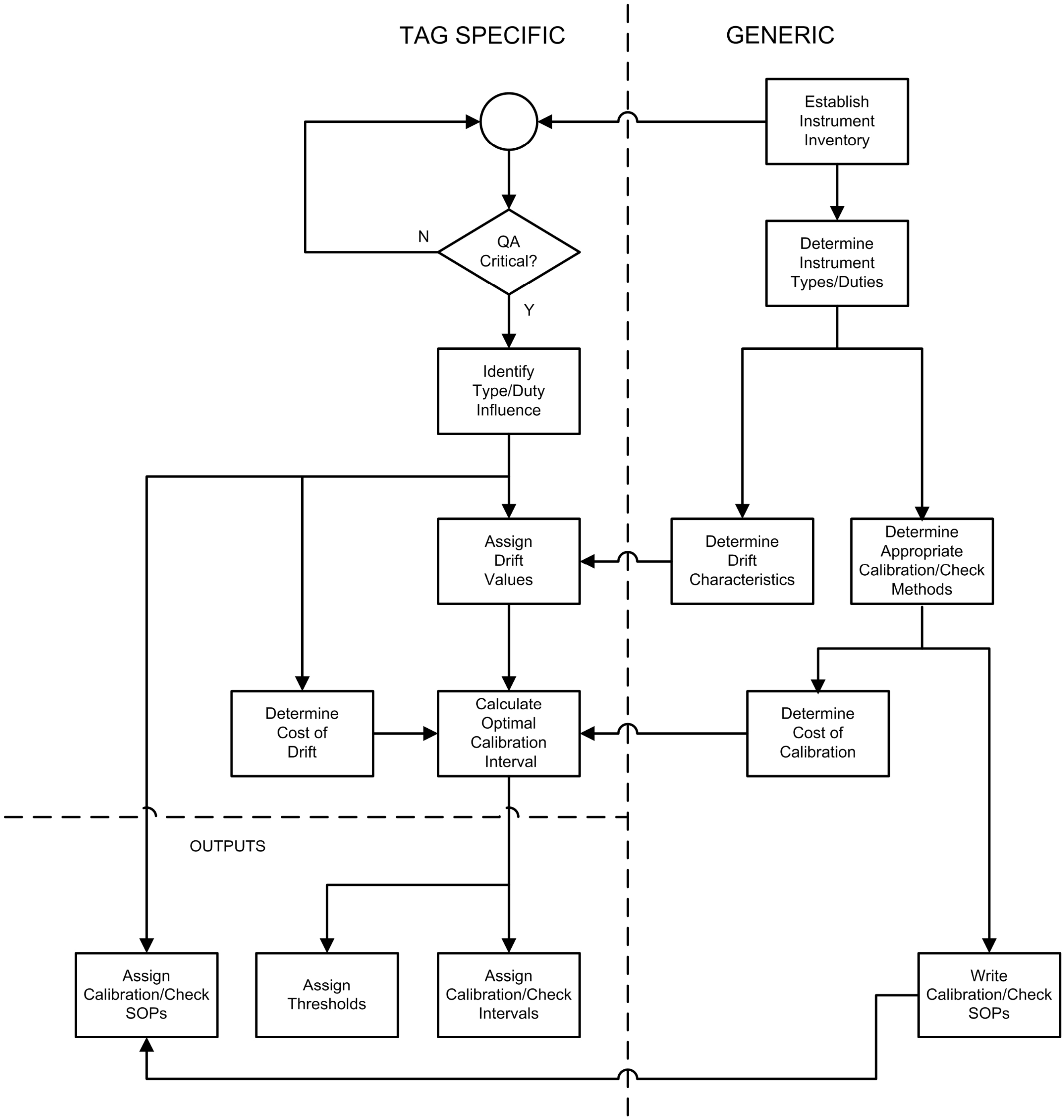

Fig.3 Refined Procedure Development Process Model

The approach produces a traceable basis for nomination of calibration requirements.

MEASUREMENT SYSTEM MANAGEMENT

Determination of calibration periods and techniques is essentially a one off exercise with minor modification as plants develop. However the proper management of measurement systems and their effective calibration is an ongoing concern.

Should calibration be performed in-house or out sourced? As long as the appropriate disciplines are maintained there is no particular virtue of one over the other, except in custody transfer applications where an outside company can bring a degree of independence that can enhance confidence for the contractual parties.

The key requirement is to identify the scope of the real calibration requirements as they relate to your business and ensure their effective execution.

Clearly proper management of measurement systems is not a trivial issue for business, but there is a real danger that the necessary focus will be displaced by other activities. Calibration routines may be skipped or they may not be performed with appropriate rigour. Standing procedures may become out dated as plant systems and technologies evolve. Diagnostic information and opportunities may be lost.

Beyond calibration concerns there are issues of spares management and measurement systems migration paths, as obsolescence erodes system capability and availability.

These considerations point to the potential value in outsourcing measurement management services for some businesses, so that they may focus their limited resources on their core activity without compromising auxiliary, but nonetheless important functions.

If choosing to outsource however, it is important to ensure that the service level matches the measurement system and business requirements. In many service activities an indifferent performance would be immediately apparent to the user who could take appropriate steps. This is not necessarily true of calibration, where indifferent performance may remain unrevealed. If a business is considering outsourcing measurement systems management, they should seek reassurance that the service provider has:

- Appropriate quality assurance procedures
- Effective ongoing management of procedures
- Commitment to proper management of associated health & safety issues
- An understanding of wider measurement system management issues such as systems obsolescence and migration paths
- Breadth of capability and resources that matches client needs

It is important to identify the service specification level. Not all calibrations are equal! The following points should be considered:

- Number of points to be checked, number of tests/runs at each point.
- Facility accreditation, traceability and uncertainty
- Value added services (e.g. On-line certificate availability, calibration equipment management, asset management etc.)
- Repair and adjustment service options
- Turn around time (Cycle time for calibration)

CONCLUSIONS

Measurement system management techniques that have been developed in response to regulatory pressures may be usefully propagated into other areas with a commercial advantage to business.

A new generation of mobile proving rigs that exploit coriolis technology are allowing the extension of in-situ proving techniques to new business sectors.

Much routine calibration activity is misplaced, with the wrong systems being calibrated, or the right systems being calibrated too frequently or with too onerous an approach. A more intelligent and discriminating approach may be used to establish an appropriate calibration regime for a process plant.

A mathematical approach (described above) may be used to help determine optimum calibration intervals.

Flawed performance in calibration and associated asset management services may remain unrevealed. Users should take care to ensure that such service functions are executed to an appropriate standard so that business performance is not compromised.

NOMENCLATURE

K	drift rate (%/year)
t	time since calibration (yrs)
P	Production rate (units/yr)
C_d	cost assigned to unit percentage drift per production unit (€/%/unit)
C_C	Cost of calibration (€)
C_{CA}	Annual cost of calibration (€)
C_{DA}	Annual cost of drift (€)
C_{A1}	Annual Cost of 1% error (€)
$MTBS$	Mean time between unrevealed shifts of magnitude S (years)
S	Calibration shift (%)
T	Calibration period (years)
L	Potential loss (€)

VITA

Harvey T. Dearden was previously employed by the CEGB, Kennedy & Donkin, National Nuclear Corporation, Foxboro GB, SGS Redwood, Costain Oil, Gas & Process, Associated Octel and Great Lakes Chemical. He is now an independent consultant providing professional engineering services to the process industries. He is a registered chartered engineer in the UK and a member of the Institution of Engineering and

Technology, and the Institute of Measurement and Control.

Peter A. Barlow has been engaged with measurement system management throughout his career. Previously employed by Shell UK, SGS Redwood, and BAE Systems, he has been employed as Services Manager for Endress+Hauser's UK operations for the last 5 years. He is a member of the Energy Institute/Institute of Petroleum and contributes to a number of working groups concerned with evaluation of new and existing measurement techniques and related codes of practice.