Uncertainty Analysis Based on Historical Data

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1 INTRODUCTION

Uncertainty analyses are essential to determine whether measurement systems are capable of meeting performance targets. They are also used to help develop maintenance and calibration schedules.

When developing uncertainty budgets for new measurement systems however it is difficult to obtain reliable data to provide evidence. In many cases manufacturer's estimates of uncertainty are used along with engineering judgement. These techniques are permitted in guidance documents such as the *Guide to the expression of Uncertainty of measurement* (GUM)[1] and ISO 5168: 2003[3]. To improve the analysis over time these uncertainty budgets should be updated with real data from calibrations and verifications of the measurement system. This data can also be used to improve maintenance and calibration schedules.

This paper will discuss the importance of regarding uncertainty analysis as an iterative process and will show how historical data can be used to improve our understanding of meter performance through the use of uncertainty budgets as more data becomes available.

An example of how historical data can improve uncertainty budgets will be shown using data from calibrations of secondary reference turbine meters at NEL.

2 UNCERTAINTY ANALYSIS BACKGROUND

2.1 Analytical Method

The analytical method of calculating uncertainty is described in detail in the GUM[1]. The technique involves a series of steps outlined below.

1. Define the relationship between all the inputs to the measurement and the final result.
2. For each input, draw up a list of all the factors that contribute to the uncertainty in that input.
3. For each of the uncertainty sources make an estimate of the magnitude of the uncertainty.
4. Convert the uncertainties to standard uncertainties by assigning a probability distribution to each uncertainty source.
5. From the relationship defined in step 1, estimate the effect that each input has on the measured result. This is usually achieved by calculating sensitivity coefficients.
6. Combine all the input uncertainties using the root sum squared technique to obtain the overall uncertainty in the final result.
   Note: If correlations exist then the inputs are combined in a different manner (see section 7).
7. Express the overall uncertainty as the interval about the measured value, within which the true value is expected to lie with the required level of confidence.

The uncertainty budgets created using the analytical method are very useful tools for optimising measurement systems as the effect of changes in input uncertainties on the output uncertainty can be seen very quickly. The input uncertainty sources can be ranked to determine which sources have the most significant effect on the overall uncertainty. The process of developing uncertainty budgets can also be beneficial in that it helps to gain a full understanding of how the measurement system works.

2.2 Monte Carlo Method

The Monte Carlo method is an alternative method of estimating measurement uncertainties. It is described in detail in supplement 1 to the GUM[2]. The method involves a series of steps outlined below.

1. Define the relationship between all the inputs to the measurement and the final result.
2. For each input, draw up a list of all the factors that contribute to the uncertainty in that input.
3. For each of the uncertainty sources make an estimate of the magnitude of the uncertainty.
4. Assign a probability distribution to each of the uncertainty sources.
5. Use a random number generator to assign a "measured value" for each input variable based on its uncertainty value and probability distribution.
6. Calculate the final result using the "measured values" as inputs.

This process is repeated tens of thousands or hundreds of thousands of times until there is enough data to analyse the output distribution. The uncertainty in the final result can then be estimated by calculating the standard deviation of the output data.

Monte Carlo has some advantages for example it shows the distribution in the output which can be used to view whether the distribution is skewed or rectangular in shape. The Monte Carlo technique is particularly useful when the uncertainties are large compared with the measured values[3] which is not the case for the example in this paper. It has previously been shown that agreement between the Monte Carlo and Analytical methods can be good as long as they are carried out correctly[4].

3 UNCERTAINTY OF NEL TURBINE REFERENCE METERS

As a way of demonstrating the benefits of using historical data in uncertainty analyses the secondary reference turbine meters for the NEL water flow calibration facility have been analysed. The water reference meters consist of two 8" turbine meters known as M2 and M3. The meters are installed in parallel with a flowrange of 30-300 l/s. At NEL the meters are used up to a maximum flowrate of 200 l/s and when used in parallel can measure up to the maximum flow of the facility which is 400 l/s. There are also low flow reference meters but they have not been analysed for this paper.

The meters are calibrated using the primary reference gravimetric weighbridges in the NEL water facilities. The meters are calibrated regularly and data is available back until 2004.

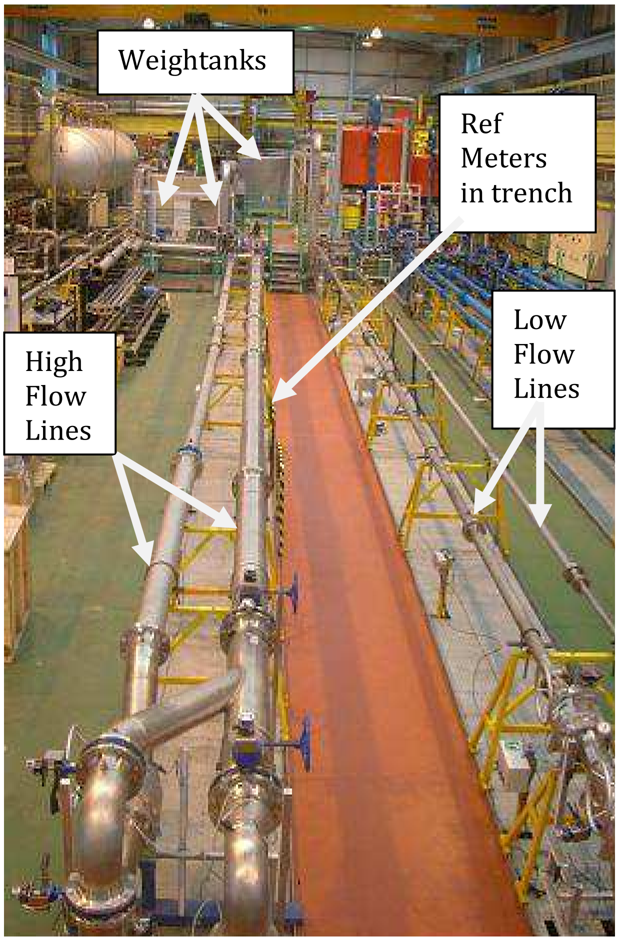

Figure 1: NEL water flow facility

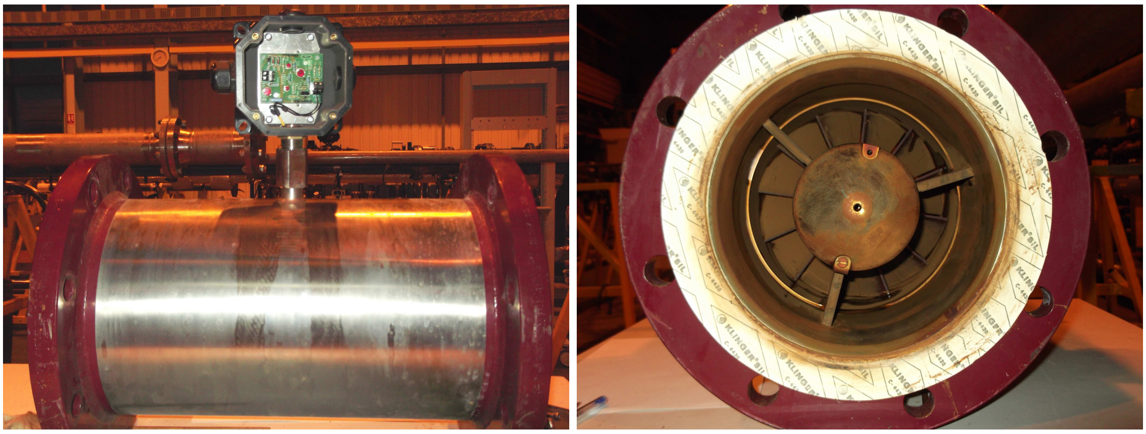

Figure 2: NEL water flow facility reference turbine meters

The aim was to determine the uncertainty in the volume which passes the reference meters during a calibration. In order to do this the first task is to list all the sources of uncertainty which contribute to the overall uncertainty in volume. The uncertainty sources identified for consideration in this analysis are described below.

Calibration: For each flowmeter the uncertainty in its calibration will contribute to the uncertainty in its use. The calibration uncertainty here is defined as the uncertainty in the reference measurements which in this case is the gravimetric weightanks used as the primary reference in the NEL water flow facility.

Curve fit: The uncertainty in curve fit is defined here as the difference between the estimated k-factor and the actual k-factor. If the k-factor is assumed to be linear or a constant value then this uncertainty source could be described as linearity. In this case however a curve fit is applied to the turbine meter k-factors to try and minimise this uncertainty source.

Drift: When flowmeters are calibrated periodically there will be an uncertainty source caused by k-factor drift between calibrations. Turbine meter k-factors can drift for many reasons including wear on the turbine blades or changes in bearing friction. This uncertainty source will reduce if calibrations are carried out more frequently.

Resolution: All measurement instruments will have an uncertainty caused by resolution. In the case of these turbine meters they have a pulsed output where a pulse is generated each time a turbine blade passes the magnetic pickup. The resolution uncertainty is therefore simply the resolution of one pulse.

Temperature/Viscosity effects: It has been shown previously that the performance of turbine meters are affected by changes in fluid viscosity[6]. This is due to an increase in the viscous shear force on the rotor which causes increased viscous drag within the bearing. Changes in viscosity can also lead to an increase in boundary layer thickness which causes non-linearity. Temperature can also affect the turbine meter performance due to changes in dimension of the meter and thermal expansion and contraction of the fluid within the meter. In this case the effects of temperature and viscosity have been combined into one uncertainty source. This uncertainty accounts for changes in temperature between calibration and use of the meter along with the stability of temperature during use.

These uncertainties will be in units of volume, k-factor or pulses. Using the analytical method they are all converted to units of volume using sensitivity coefficients before being combined using the root sum squared technique.

Meters M2 and M3 are installed in parallel and when used together covariances or correlations will exist between some of the uncertainty sources since they are calibrated against the same reference and they have identical designs. Where correlation exists the sources are combined with straight addition rather than the root sum square technique.

4 UNCERTAINTY ANALYSIS WITH NO HISTORICAL DATA

An uncertainty analysis was first completed assuming that no historical data was available. This is a common occurrence for example where the measurement system is newly installed or if the historical data has not been well documented or is missing.

If no historical data is available then estimates of the magnitude of uncertainty sources has to be made using manufacturers specifications, engineering judgement or based on data from similar measurement systems. Figure 2 shows the uncertainty budget for meter M2 where no historical data is available. With no historical data available the uncertainty budget will be identical for meter M3.

Table 1: M2 uncertainty budget with no historical data

Rank	Uncertainty Source	Units	Value	Expanded Uncertainty U	Relative Uncertainty U* (%)	Divisor	Standard Uncertainty u	Sensitivity Coefficient c	Output Uncertainty u.c	Uncertainty Squared $(u.c)^2$
2	Calibration	m^3	9833	7.8663	0.080	2.00	3.9331	1	3.93E+00	1.55E+01
1	Curve fit/linearity	P/m^3	1.017	0.0015	0.150	2.00	0.0008	-9668	-7.37E+00	5.44E+01
3	Drift	P/m^3	1.017	0.0004	0.035	1.73	0.0002	-9668	-1.99E+00	3.96E+00
5	Resolution	Pulses	10000	1.0000	0.010	1.73	0.5774	0.0001	5.77E-05	3.33E-09
4	Temp/viscosity effect	P/m3	1.017	0.0001	0.005	2.00	0.0000	-9668	-2.46E-01	6.04E-02
	Overall Uncertainty	m^3	9833	17.190	0.175	2.00	8.595	1	8.595	73.873

The estimated magnitudes of the uncertainty sources for meter M2 are described in sections 4.1 – 4.5.

4.1 Calibration

The calibration uncertainty is taken here as the uncertainty of the NEL water flow facility primary reference which is 0.08%. This information should always be available even if the meter is new because there should be details of an initial calibration or a factory acceptance test from the manufacturer which will include an uncertainty figure.

4.2 Curve Fit

If no historical data is available then it is difficult to obtain a figure of uncertainty for curve fit. The manufacturer’s data sheet in this case quotes a figure of 0.15% for accuracy. This is technically an incorrect statement because accuracy is a qualitative term and therefore should not be assigned a value. It is not clear how the manufacturer defines accuracy in this case but it is assumed to be defined as the difference between actual and estimated k-factor. Therefore the figure of 0.15% is assumed to be the curve fit uncertainty.

4.3 Drift

It is not possible to obtain an uncertainty figure for drift if no historical data is available. It therefore has to be estimated from engineering judgement or from experience of similar instruments. In this case the value of 0.035% is taken from the uncertainty caused by drift in the NEL oil flow facility reference turbine meters.

4.4 Resolution

The resolution uncertainty is simply the resolution of one pulse. If it is assumed that 10000 pulses are taken then the uncertainty is 0.01%. This source of uncertainty should be insignificant unless a smaller number of pulses are taken. It is generally recommended that at least 10000 pulses are collected unless pulse interpolation is being used.[8]

4.5 Temperature/Viscosity Effects

It is difficult to obtain a value for uncertainty caused by temperature or viscosity effects unless calibrations have been carried out at different temperatures and viscosities. In this case no figures were available from the manufacturer on temperature/viscosity effects.

Published data[7] on a 6” turbine meter in water was available however and the meter was found to have a variation in k-factor of around 0.005% per °C. With a lack of additional information the uncertainty due to temperature/viscosity effects was assumed to be 0.005% multiplied by the difference in temperature between calibration and use of the meter plus the temperature stability in use.

5 UNCERTAINTY ANALYSIS WITH HISTORICAL DATA

An uncertainty analysis was then carried out for meters M2 and M3 using the historical data. Table 2 shows the uncertainty budget for meter M2 when historical data was available.

Table 2: M2 uncertainty budget with historical data

Rank	Uncertainty Source	Units	Value	Expanded Uncertainty U	Relative Uncertainty U* (%)	Divisor	Standard Uncertainty u	Sensitivity Coefficient c	Output Uncertainty u.c	Uncertainty Squared $(u.c)^2$
1	Calibration	m^3	9833	7.8663	0.080	2.00	3.9331	1	3.93E+00	1.55E+01
3	Curve Fit (linearity)	P/m^3	1.017	0.0003	0.030	2.00	0.0002	-9668	-1.47E+00	2.18E+00
2	Drift	P/m^3	1.017	0.0006	0.060	1.73	0.0004	-9668	-3.41E+00	1.16E+01
5	Resolution	Pulses	10000	1.0000	0.010	1.73	0.5774	0.0001	5.77E-05	3.33E-09
4	Temperature/viscosity effect	P/m3	1.017	0.0001	0.006	2.00	0.0000	-9668	-2.95E-01	8.70E-02
	Overall Uncertainty	m^3	9833	10.837	0.1102	2.00	5.419	1	5.419	29.362

Sections 5.1 – 5.5 shows the analysis carried out to determine the magnitude of the uncertainty sources in meter M2. An identical exercise was also completed for meter M3 and the uncertainty budget can be seen in section 7.

5.1 Calibration

The calibration uncertainty is the same whether historical data is available or not. In this case it is taken as the uncertainty of the NEL water flow facility primary reference which is 0.08%. This figure has been determined from an uncertainty analysis using data collected over a number of years.

5.2 Curve Fit

An example polynomial curve fit for reference meter M2 is shown in figure 3. It can be seen that curve fit errors will be caused from the difference between the actual k-factor and the calculated k-factor based on the polynomial curve.

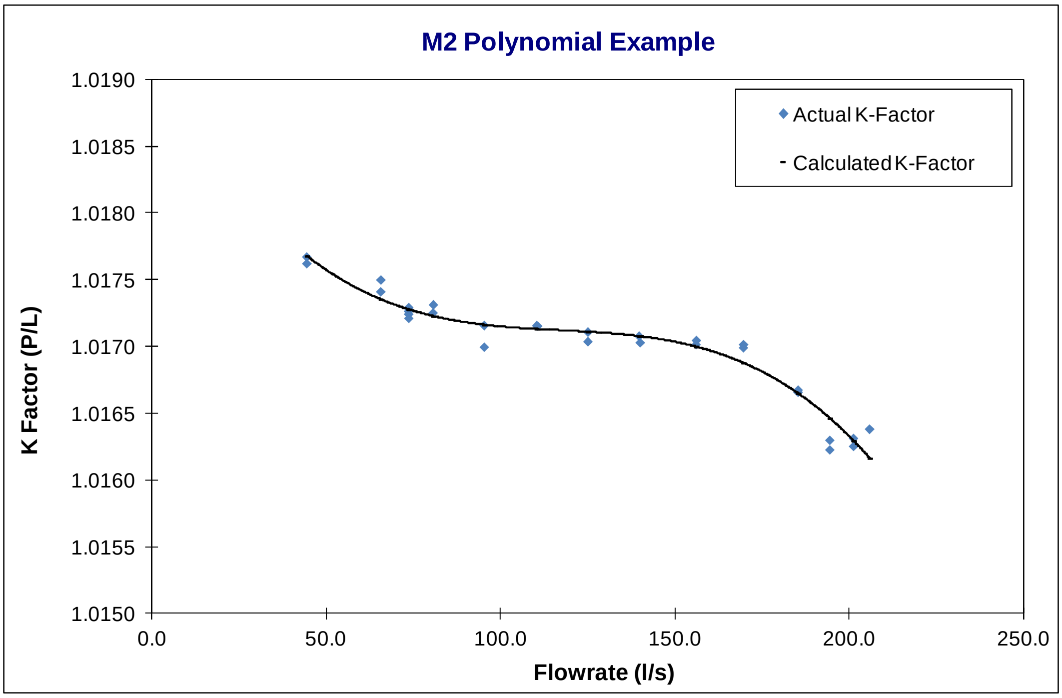

Figure 3: M2 example polynomial

Figure 4 shows all the curve fit errors for the calibrations from 2008 to present. It should be noted that data on the polynomial curves were not available from 2004 to 2008. The curve fit error data was analysed and it was found that 95% of the errors were within ±0.03%. Therefore the uncertainty caused by curve fit error was assumed to be ±0.03% at a confidence level of 95%.

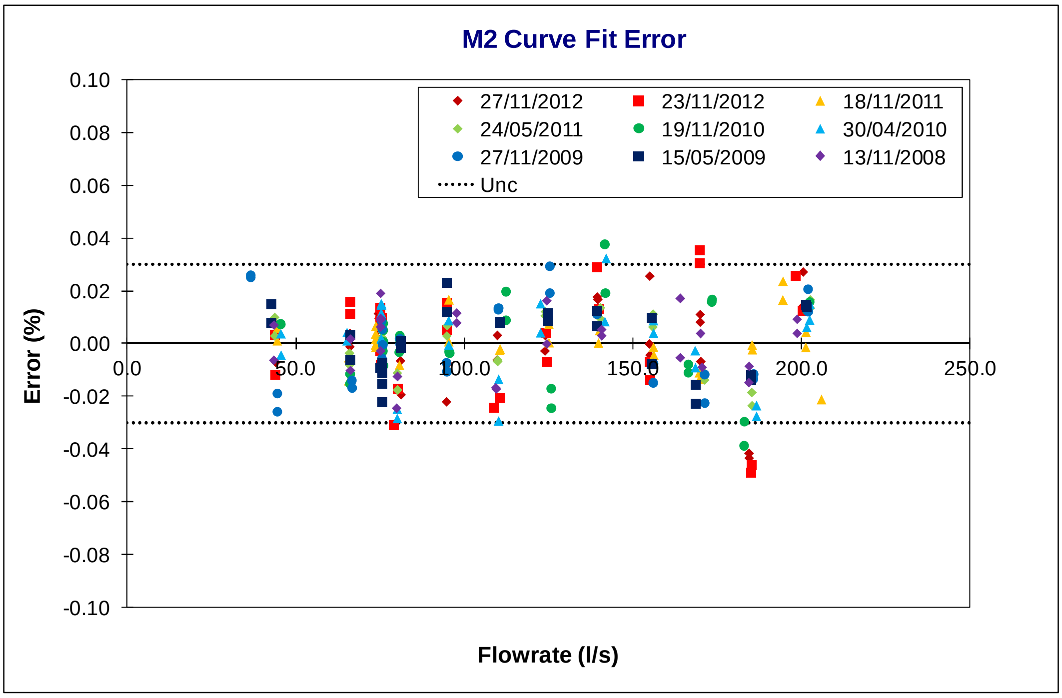

Figure 4: M2 curve fit errors

5.3 Drift

Figure 5 shows the calibration results for reference meter M2 from 2004 to present. As expected there is a spread of results and there appears to be a drift in k-factor. If there is drift in k-factor between calibrations then this will lead to uncertainty. It therefore has to be accounted for in the uncertainty budget.

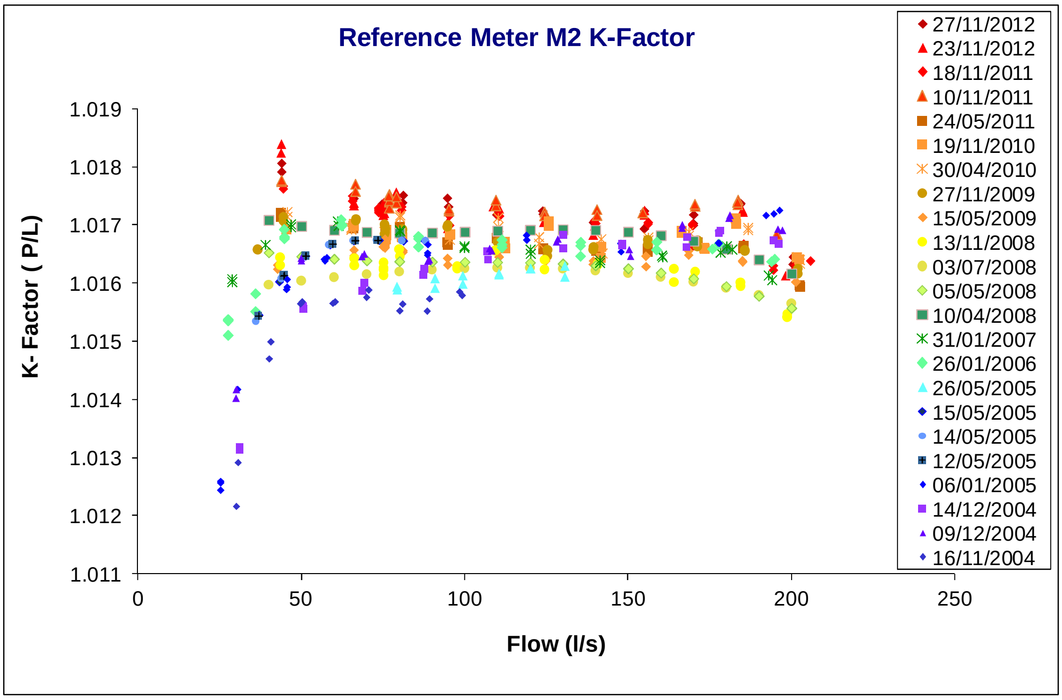

Figure 5: M2 K-factor 2004 to present

An average k-factor was calculated for each calibration from 2004 to present and this is plotted in figure 6. It can be seen that there is a general trend in that the k-factor appears to be increasing over time. However from one calibration to the next the k-factor both increases and decreases. An uncertainty can therefore be assigned to drift but there is equal probability as to where the k-factor will drift within this uncertainty band. Therefore a rectangular probability distribution has been assigned to drift.

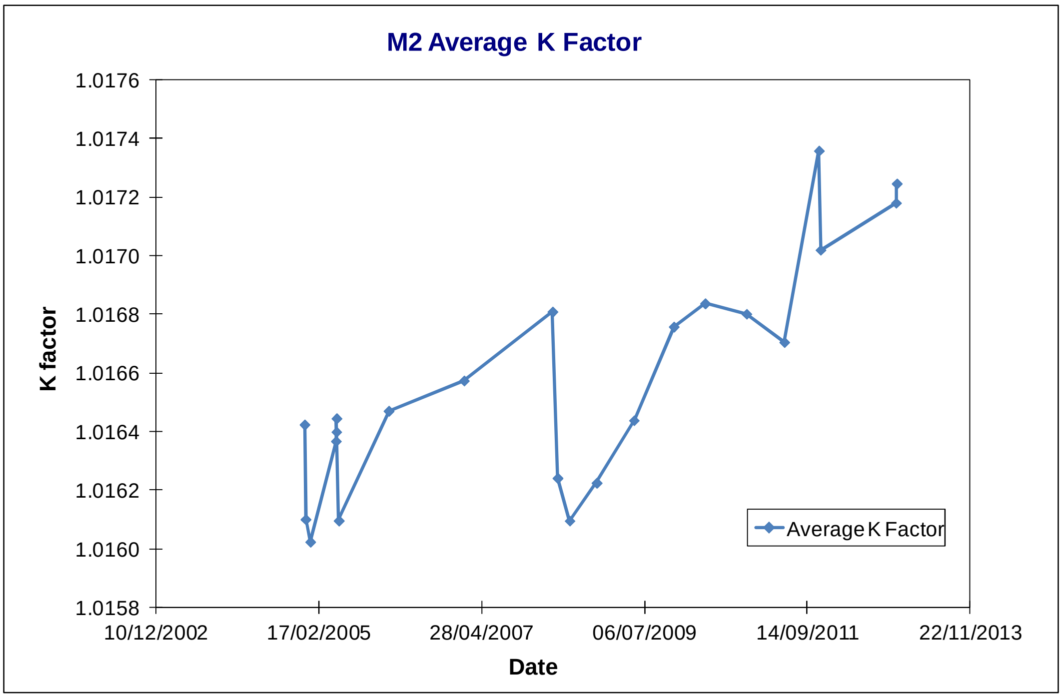

Figure 6: M2 average k-factor

Figure 7 shows the drift of the polynomial curves from the previous calibration of meter M2. It can be seen that 95% of the data points are within ±0.06%. The drift uncertainty was therefore assumed to be ±0.06% at a confidence level of 95%.

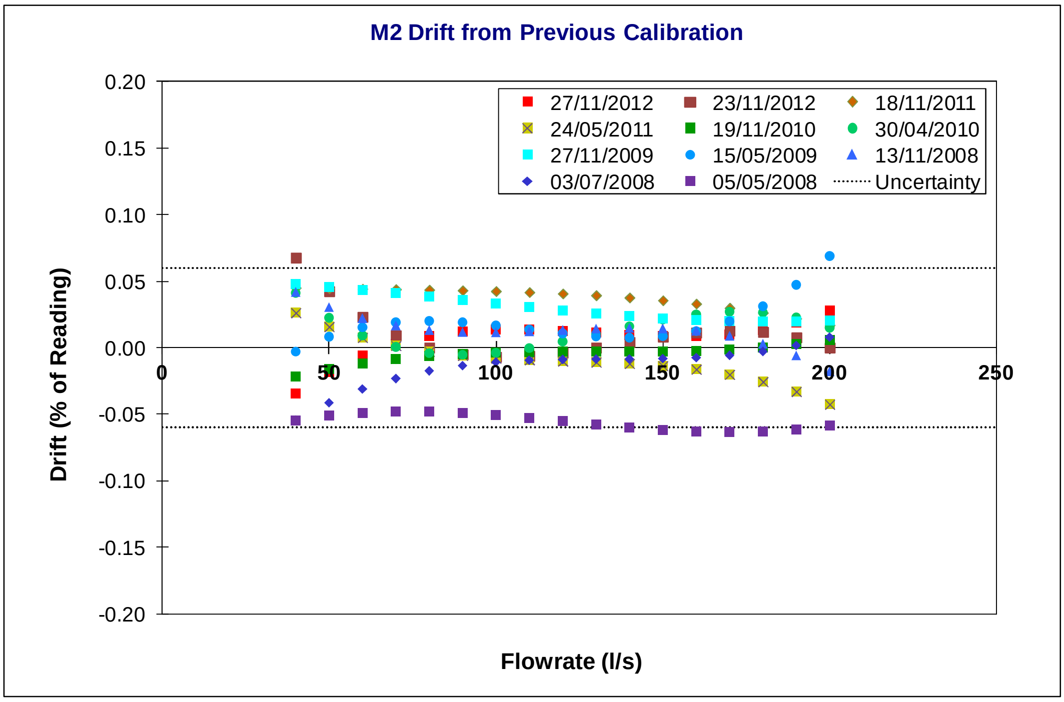

Figure 7: M2 Drift from previous calibration

5.4 Resolution

The resolution is simply the resolution of one pulse and as a minimum of 10000 pulses are taken at NEL this means the resolution will be a maximum of 0.01%. Resolution uncertainties have a rectangular probability distribution because within the uncertainty limits no value is more likely than another.

5.5 Temperature/Viscosity Effects

Turbine meters are known to be affected by temperature and viscosity changes. Figure 8 shows the k-factor of meter M2 at 20°C, 34°C and 40°C. Although ideally more data would be available there appears to be a trend where the k-factor decreases as the temperature increases.

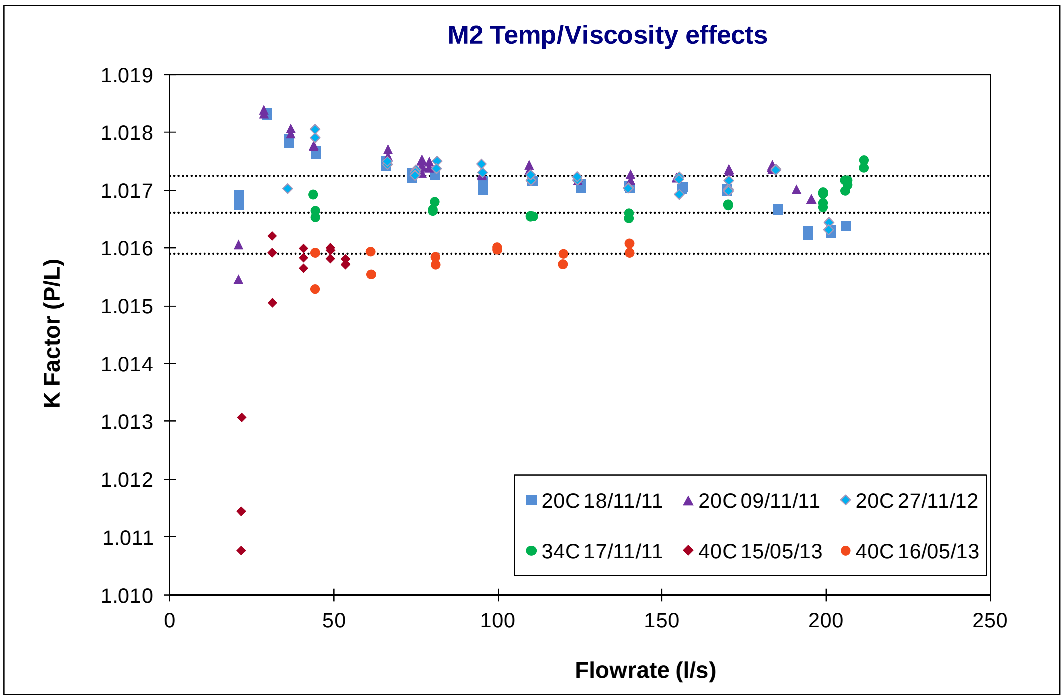

Figure 8: M2 k-factor at various temperatures

The k-factors were then averaged for each temperature and plotted as shown in figure 9. A linear relationship between k-factor and temperature was assumed and it could then be calculated that the k-factor reduces by 0.006% for every 1°C rise in temperature.

The uncertainty is calculated by firstly calculating the temperature change which is the difference in temperature between calibration and use of the meter plus the temperature stability in use. This is then multiplied by 0.006 to determine the uncertainty in k-factor caused by the combined temperature and viscosity effect on the turbine meter.

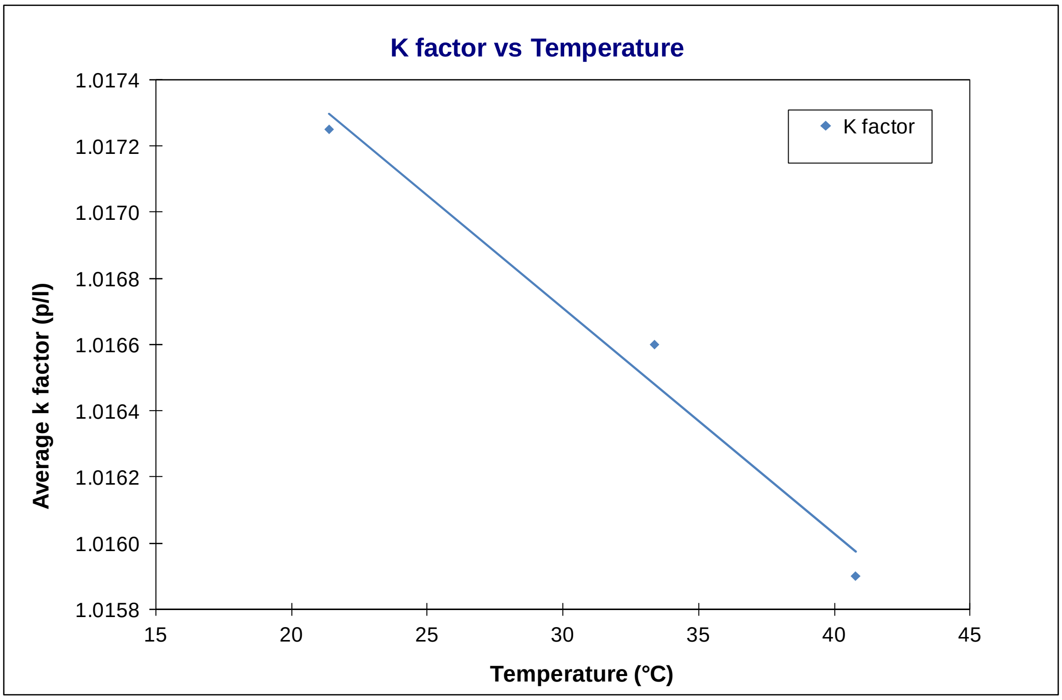

Figure 9: Average k-factor vs temperature

5.6 Repeatability

It can be argued that an uncertainty source due to non-repeatability should also be included in uncertainty budgets for flowmeters. However ISO 5168[3] states that:

Meter performance characteristics such as non-repeatability are included in the curve fit uncertainty because the curve is necessaririly based on multiple readings.

To test this theory a series of twenty repeat points were taken at 60 l/s during a calibration. It can be seen in figure 9 that all of these repeat points were within the curve fit uncertainty of 0.03%. Therefore it is assumed that uncertainty due to non-repeatability is included in the curve fit uncertainty.

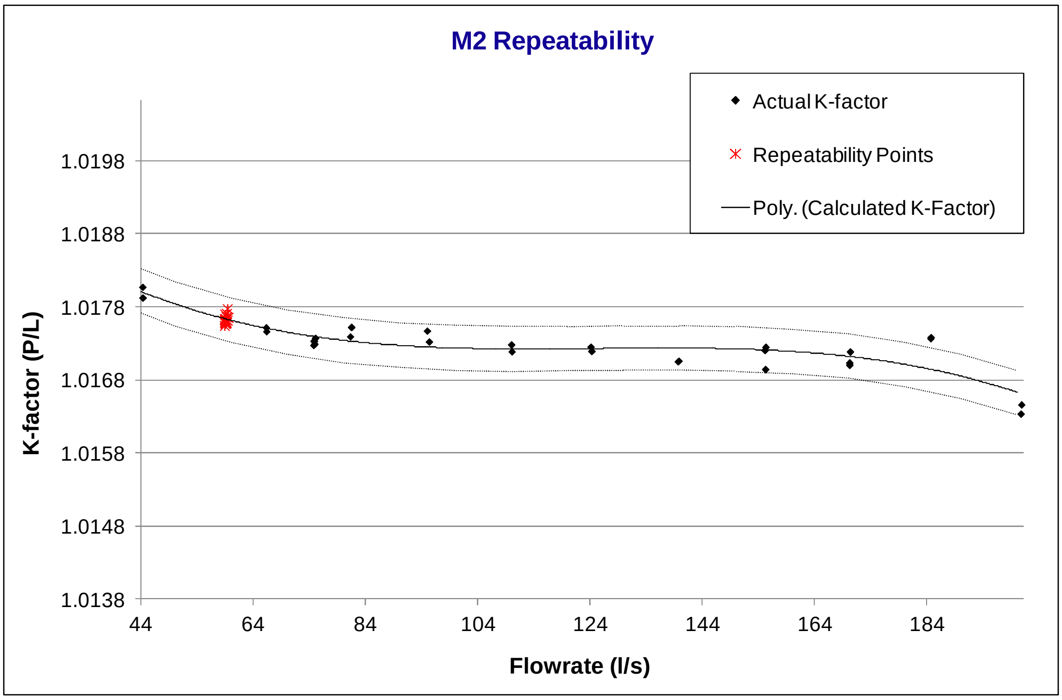

Figure 10: M2 Repeatability test

6 MONTE CARLO METHOD

It has been shown previously that the combined use of the analytical and Monte Carlo methods of uncertainty analysis can be useful[4]. The advantages of carrying out both methods on the same system are as follows:

- The Monte Carlo and analytical methods can be used to cross check against each other.
- The Monte Carlo method can be used to show if the output distribution is skewed or rectangular.
- The Monte Carlo method can be used to ensure that covariances are being accounted for in the analytical method.
- The analytical method can then be used to carry out what if analyses which will show the effects of changes in the input parameters on the overall uncertainty of the system.

Comparing the two methods is particularly useful when uncertainties are large compared to the measured values when the mathematical theory in the analytical method can break down.[8] This is not the case for the example of the NEL reference meters but the two methods have been compared here for illustration purposes.

The Monte Carlo method of uncertainty analysis has been used in this case to calculate the uncertainty of the NEL reference meters. The analysis was performed in Excel using 10,000 iterations.

Figure 11 shows the output distribution for meter M2. It can be seen that the distribution is close to a normal distribution and does not have significant skewness. This can be proven by using skewness and kurtosis tests to determine the relative degree of asymmetry and flatness in the output distribution compared to the normal distribution. Therefore in this case the assumption of a normal output distribution made in the analytical method is considered acceptable.

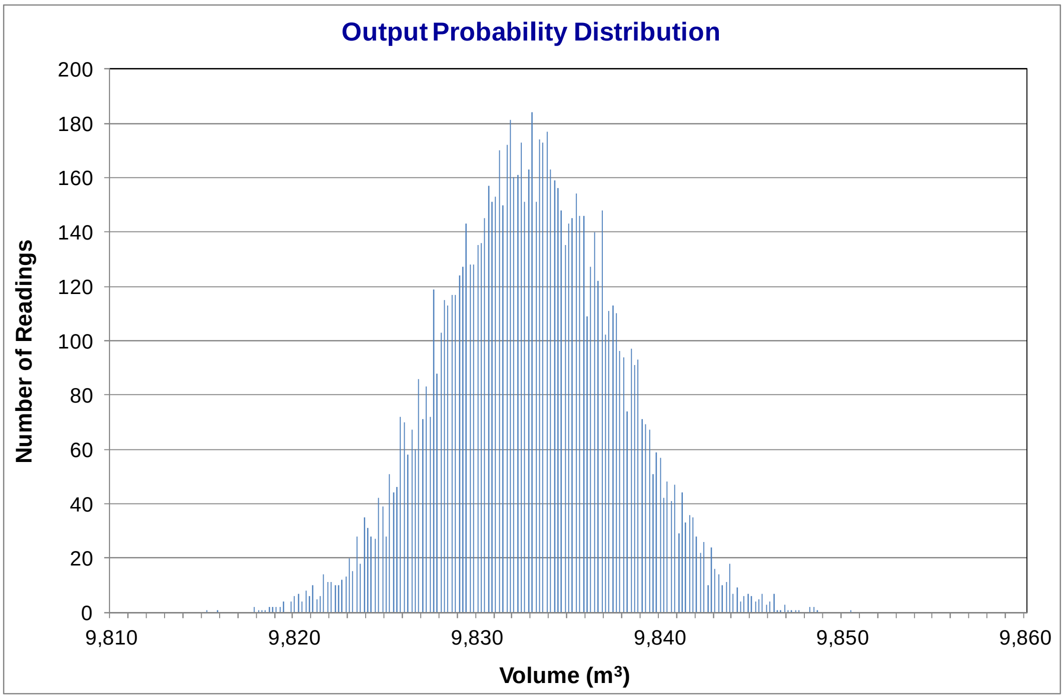

Figure 11: M2 output probability distribution

Table 3 shows the comparison between the analytical and Monte Carlo methods to calculate the uncertainty of meter M2. It can be seen that the agreement is within 0.015%. This agreement helps to increase confidence in the uncertainty calculation.

Table 3: Comparison between analytical and Monte Carlo methods

Method Used	Expanded Uncertainty (m3)	Expanded Uncertainty (%)
Analytical Method	10.837	0.110
Monte Carlo Method	9.311	0.095
Difference	1.52	0.015

7 USE OF METERS IN PARALLEL

If the flowrate is higher than 200 l/s in the NEL water flow facility then reference meters M2 and M3 are used in parallel. If meters are used in parallel then correlation or covariance have to be accounted for.

Correlated uncertainties are combined arithmetically rather than using the root sum square technique which is generally used in the analytical method.

In this case the calibration uncertainties are fully correlated because both meters are calibrated against the same reference. The curve fit, drift and temp/viscosity effect uncertainties are assumed to be partially correlated. This is because the meters are of the same manufacturer, model and size and are therefore expected to be affected in similar ways but turbine meters do have some degree of individuality due to manufacturing tolerances.

The uncertainty budget for meters M2 and M3 when used in parallel is shown in table 4.

Table 4: Uncertainty budget for M2 and M3 used in parallel

UNCERTAINTY IN M2

Uncertainty Source	Units	Value	Expanded Uncertainty U	Relative Uncertainty U* (%)	Uncertainty Squared $(u.c)^2$	Correl. %	Correlated u.c	Correlated (u.c)^2	Uncorrelated u.c	Uncorrelated (u.c)^2
Calibration	m^3	9833	7.8663	0.080	1.55E+01	100	3.93	15.47	0	0
Curve Fit (linearity)	P/m^3	1.017	0.0003	0.030	2.18E+00	50	-0.74	0.54	-0.74	0.54
Drift	P/m^3	1.017	0.0006	0.060	1.16E+01	75	-2.56	6.54	-0.85	0.73
Resolution	Pulses	10000	1.0000	0.010	3.33E-09	0	0	0	5.8E-05	3.3E-09
Temp/viscosity effect	P/m3	1.017	0.0001	0.006	8.70E-02	20	-0.06	0.00	-0.24	0.06
Overall Uncertainty	m^3	9833	10.837	0.1102	29.362	N/A				

UNCERTAINTY IN M3

Uncertainty Source	Units	Value	Expanded Uncertainty U	Relative Uncertainty U* (%)	Uncertainty Squared $(u.c)^2$	Correl. %	Correlated u.c	Correlated (u.c)^2	Uncorrelated u.c	Uncorrelated (u.c)^2
Calibration	m^3	10040	8.0321	0.080	16.129	100	4.02	16.13	0	0
Curve Fit (linearity)	P/m^3	0.996	0.0003	0.030	2.086	50	-0.72	0.52	-0.72	0.52
Drift	P/m^3	0.996	0.0007	0.068	14.327	75	-2.84	8.06	-0.95	0.90
Resolution	Pulses	10000	1.0000	0.010	3.33E-09	0	0	0	5.8E-05	3.3E-09
Temp/viscosity effect	P/m3	0.996	0.0000	0.004	0.037	20	-0.04	0.00	-0.15	0.02
Overall Uncertainty	m^3	10040	11.416	0.1137	32.580	N/A				

UNCERTAINTY IN REFERENCE METERS M2 & M3 IN PARALLEL

					Taken from appropriate meters			
					Arithmetic sum of u.c		Rt sum squares	
Uncertainty Source	Units	Value	Expanded Uncertainty U	Percentage Uncertainty U* (%)	Correlated u.c	(u.c)^2	Uncorrelated u.c	(u.c)^2
Calibration	m^3				7.95	63.19	0	0
Curve Fit (linearity)	P/m^3				-1.46	2.13	1.03	1.07
Drift	P/m^3				-5.40	29.12	1.27	1.62
Resolution	Pulses				0	0	8.2E-05	6.7E-09
Temp/viscosity effect	P/m3				-9.8E-02	9.5E-03	0.28	0.08
Overall Uncertainty	m^3	19873	19.720	0.099	9.72	94.45	1.66	2.77

8 BENEFITS OF USING HISTORICAL DATA

It is clear that using historical data to carry out uncertainty analyses leads to many advantages.

It will allow the operator to determine a more accurate estimation of uncertainty on measurement systems. Other methods of estimating uncertainty sources such as using manufacturer's specifications, the engineering judgement of experts or data from similar systems are all acceptable in the GUM. However the assumptions made using these methods will lead to a less accurate estimation of uncertainty.

Having an accurate, evidence based estimation of uncertainty for a measurement system will allow cost effective improvements to be made to the system in the future. The uncertainty sources can be ranked to determine which sources contribute most to the overall uncertainty in the system. The uncertainty of these sources can then be improved first before time and money is wasted on improving the uncertainty of insignificant sources. If historical data is not used then the uncertainty budget will not be as accurate and it will be more difficult to determine the most significant sources. This is shown by the example in this paper where the most significant source is different depending on whether historical data is used or not.

The process of analysing historical data will also bring benefits to the maintenance teams. Typically, maintenance (including verifications and calibrations) is carried out very frequently especially when a new system is installed. The frequency can be reduced over time if the instrument passes verification checks.

By analysing the stability of instruments over a period of time however calibration schedules can be determined based on evidence rather than choosing arbitrary time periods. Less stable instruments can be calibrated more frequently and more stable instruments can be calibrated less frequently. If new systems are installed with identical equipment then evidence will be available for determining initial calibration schedules.

This will help to save money and improve accuracy of measurement systems over long periods of time. If the stability of instruments is likely to reduce over time then it will also help determine when these instruments need to be replaced.

If the frequency of calibration on more stable instruments can be reduced then it will also lead to improved safety procedures as it will avoid the need to break into the line which involves isolation and depressurisation.

Using historical data to carry out uncertainty analyses will not only benefit the company operating the measurement system but will also benefit the industry as a whole. Increased knowledge of the uncertainty of measurement systems will lead to more effective allocation principles in shared pipelines. It will also help regulators to set regulations which are suitable and achievable based on current industry best practice.

9 CONCLUSIONS AND RECOMMENDATIONS

The analysis carried out in this paper has shown that the estimation of uncertainty in measurement systems can be greatly improved when historical data is available. The estimated uncertainty for the NEL reference meters when no historical data was available was 0.07% higher than when historical data was available. If this difference was applied to a large North Sea oil field producing 50,000 bbl/day then the overestimation of uncertainty would equate to a monetary value of $1.5m per year assuming an oil price of $120/bbl.

This paper makes the following recommendations:

- Historical data should be used whenever possible to estimate uncertainty sources.

- Historical records of calibrations should be kept in good order so that they can be analysed at regular intervals. This should already be the case if the system is audited and therefore should not be difficult to achieve.

- Uncertainty analysis should be seen as an iterative process and uncertainty budgets should be updated whenever new calibration data is available or changes are made to measurement system. It is recommended that as a minimum uncertainty budgets should be reviewed annually to ensure they are still relevant and accurate.

- If a system is new or calibration data is not available then uncertainty sources can be estimated by other methods. However the uncertainty values should be updated over time as more historical data becomes available.

- It is recommended that manufacturers make available more data on the performance and stability of instruments over time. Performance data is generally available on the manufacturer's data sheet but different manufacturers present the data in different forms, a coverage factor is not always given and the stability of the instrument over time is not always given. It is understandable that these data sheets are used for marketing and need to be concise but as a minimum the data should be readily available on request. This will allow more accurate estimates of uncertainty when historical data is not available.

- It is also recommended that more sharing of data is carried out throughout industry. This will lead to better understanding of measurement systems which will be beneficial for buyers, sellers and pipeline users. This paper recommends the development of a database of calibration data as described in section 10.

10 DEVELOPMENT OF CALIBRATION DATABASE

A paper by B Peebles at the North Sea Flow Measurement Workshop in 2012[5] recommended the development of a national database *"to capture all UKAS calibration data for instruments and flow meters to provide the information required to monitor and enhance our knowledge and understanding of failure rates and subsequent availability analyses"*.

NEL agree that such a database would be very beneficial to the industry as a whole especially when specifying and selecting new equipment. This paper suggests that this could be carried out in three stages:

Stage 1: In addition to the calibration of flowmeters, a single company's calibration data could be analysed over a period of time similar to the analysis carried out in this paper. This could also be carried out on past data if the data is available and in a suitable format.

Stage 2: If companies agree to share data then the data from more than one operating company could be analysed and shared. This will increase the amount of knowledge about the performance of commonly used measurement devices in the oil and gas industry.

Stage 3: If enough companies become involved then a database will be developed to show the analysis of calibration and verification data for a number of companies with calibration data from various calibration laboratories.

If the database is developed to stage 3 then it could be used in two ways. Firstly a company could use it to view information on their own individual instruments. The data on individual instruments could be protected to maintain confidentiality.

The second way it could be used is to view all the analysed data for a particular type of or model of instrument. This would allow companies to make evidence based decisions about the uncertainty, maintenance and calibration schedules when installing new equipment or when historical data is not available.

Figures 12 and 13 shows how the calibration database front page could look when used in these two ways. It should be noted that the information shown is for illustration purposes only to show the type of information that could be available in the database.

CALIBRATION AND UNCERTAINTY DATABASE: TOP LEVEL

TOP LEVEL SHEET

Inputs	
Analysis Type	Individual Instrument
Company	NEL
Serial Number	123456789

Instrument Information	
Instrument	Turbine Flowmeter
Manufacturer	Manufacturer A
Model	Model 1
Size	8"
Date of Installation	16/11/2004
Number of Calibrations	23
Last Calibration	27/11/2012
Current K Factor	1.017 p/l

Uncertainty Information		Units
Most Recent Calibration Lab	NEL	
Calibration Uncertainty	0.080	%
Curve fit uncertainty	0.030	%
Curve fit (last calibration)	0.025	%
Drift Uncertainty	0.060	%
Drift (last calibration)	0.040	%
Temperature/Viscosity effect	0.006	%
Calculated Uncertainty	0.1102	%

Figure 12: Calibration database front page example (individual instrument)

CALIBRATION AND UNCERTAINTY DATABASE: TOP LEVEL

Inputs	
Analysis Type	Instrument Type
Instrument Type	Coriolis Meter
Manufacturer	Manufacturer A
Model	Model 1
Size	3"

Instrument Information	
Number of calibrations in database	105
First Calibration	10/10/2005
Last Calibration	20/09/2013

Uncertainty Information		Units
Average curve fit error	0.10	%
Average drift between calibrations	0.080	%
Uncertainty due to temperature effect (per °C)	0.001	%
Uncertyainty due to pressure effect (per bar)	0.020	%

Figure 13: Calibration database front page example (All data for model)

If enough calibration data is collated and analysed then good quality evidence based estimates of uncertainty will be made possible on all commonly used measurement equipment in the oil and gas industry. Clearly there would be technical and contractual obstacles to overcome to create such a database but it would ultimately be mutually beneficial to all those involved and could lead to improved understanding of the uncertainty of measurement systems used in the North Sea.

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