Paper 1.3

Quantifying Financial Exposure Due to Meter Uncertainty Using Monte Carlo Simulation

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QUANTIFYING FINANCIAL EXPOSURE DUE TO METER UNCERTAINTY USING MONTE CARLO SIMULATION

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1   INTRODUCTION

This paper details the steps undertaken and the thought processes followed in the design and delivery of a 'user friendly' exposure software tool. The developed tool was intended to give the user an appreciation of exposure in financial and quantity based terms as a consequence of physical and contractual conditions applicable to both the complete system and also at each node within the system.

The ability to easily and reliably quantify financial exposure (potential lost revenue) due to oil and gas flow meter uncertainties within gas and oil production fields is regarded as a valuable asset by many shippers. This is especially true for shippers who regularly deal with high oil and gas flow rates through key fiscal meters, which are in turn used as the basis for billing and accounts.

An example of a generic exposure model, representing a typical fiscal meter and associated flow-metered pipelines is detailed. An expression for financial exposure is derived from this model in terms of key domain and market attributes, including metered flow rates, meter biases, random uncertainties, equity shares (percentage take of production), taxation rates and other variables. The model has also been expanded to support the modelling of virtual meters to accommodate the scenario in which there is no telemetry for a particular meter.

2   BUSINESS BENEFITS

A dual requirement for support tools based on project and operating requirements inspired the initial concept for the exposure quantification software. The project requirement encompassed the need to be able to determine how much to spend on a new system based on defined deliverables and life cycle returns. The idea was to enable the user to manipulate input parameters and obtain an estimate of life cycle costing – thus allowing the project team to optimise the design of the metering system to meet the required specifications whilst determining the best-cost solution. The second requirement was based on the need to help managers understand the consequences of decisions in the short and longer term as a function of product quantity and value. Also to help system managers understand the consequences of third party system performance and equity difference implications.

As each system evolved it became evident that the exposure model elements were similar and could be combined into the one package. After engagement of the key stakeholders on the concept and expectation, it became evident that the input requirements would be at a detail that would potentially need engineering knowledge; conversely the output requirements were simple in terms of visual representation of geographical area with quantification of exposure.

The full value of the tool can be realised by moving away from a stand alone package to one that is loaded on the network so any manager can access to see how their systems are performing and which particular nodes have most exposure. Thus allowing decisions on resource usage to be made with sound supporting information.

3   TOOL OVERVIEW

The prototype exposure calculator tool (implemented using Microsoft's Visual Basic for Applications language - VBA) allows the uncertainty of interrelated meters to be expressed in terms of normal or triangular random error distributions and configurable bias functions thus allowing utilisation of Monte Carlo Simulation to generate likely monetary and non-monetary exposures for a shipper. The output exposure figures can be used to help identify under performing site meters.

As well as reporting detailed statistics from the simulation, the tool allows the financial exposures to be graphically displayed on an interactive map in the form of a configurable green, amber, red traffic light status scheme. This satisfies both operator and managerial requirements by allowing financial exposure results to be viewed at different levels of detail.

Key features of the exposure calculator are listed below.

- Calculation of financial exposure due to meter uncertainty at installation and field levels.

- Non-monetary and monetary exposure results output (with user defined confidence level).

- Configurable meter accuracy and precision parameters via a dedicated meter error definition form.

- Easy switching between default and custom meter parameters allowing 'what if scenarios' while preserving protected default information.

- Modelling of flow rate dependent bias and flow rate dependent random uncertainties.

- Intelligent modelling of virtual meters.

- Adoption of a Monte Carlo Simulation Engine enabling generic processing of a variety of meter error distributions (Normal and triangular are currently supported).

- Intuitive interactive map with colour coded exposure status results.

- User definable 'traffic light' limits, where the user can define what monetary exposure value constitute a high, medium or low risk for each installation.

- Built-in utility to facilitate adding new installation labels to the main map (eliminating the need for coding).

- Easy modification of global oil and gas unit prices.

- Easy cycling through installation Group or installation site details (in alphabetical order) via the Main GUI.

- Optional export of results and associated user inputs for reliable auditing.

- Editable 'General information' forms for each installation and field to hold non-simulation dependant text.

- Built-in (expandable) user help.

- Hidden and restricted data areas accessible by user defined passwords.

- Comprehensive and configurable data validation and connectivity diagnostic capabilities.

- Modularisation of business logic in hidden and protected VBA modules.

3.1   Tool Layout

In summary, there are two main user interfaces; these are the interactive map and the main Guest/Global User interface (GUI).

3.1.1   Interactive Map

The Map sheet displays an interactive schematic of the financial exposure for each installation via a three level colour coding hierarchy. The user can easily toggle between the financial exposure status for oil and for gas by checking the appropriate check box.

Note: The diagrams shown are based on fictitious or unpopulated data and do not represent actual conditions.
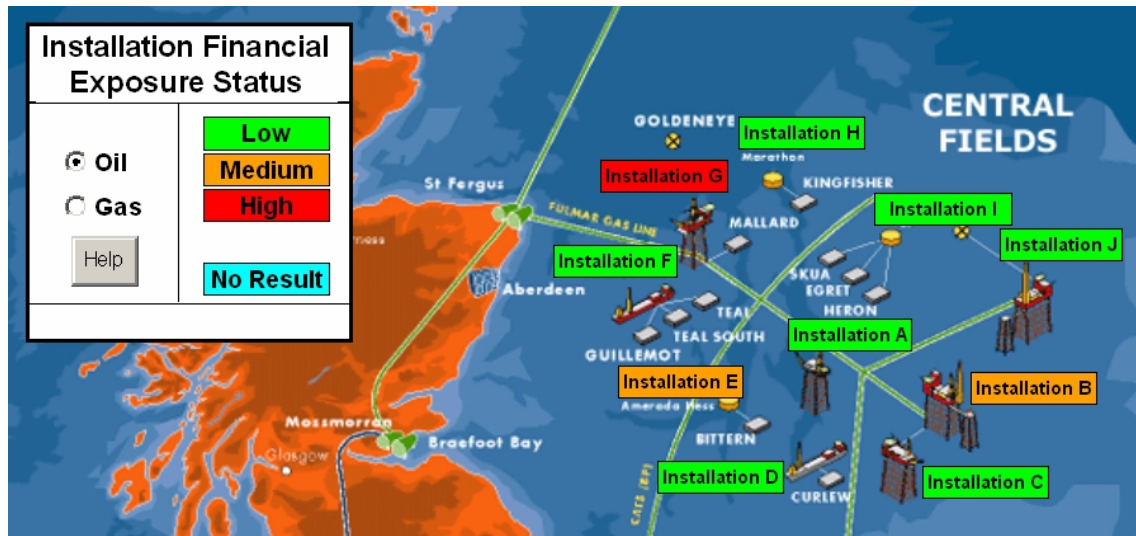

Fig. 1 – Partial screen shot of the main interactive map (central fields only)

Clicking on a particular installation label of interest launches the Main GUI interface where the user can view or modify the low-level installation details.

Table 1 gives a description of the exposure status key, which can be seen toward the upper left of Fig. 1.

Table 1		Map – Financial Exposure Status Legend
Exposure Status	**Colour Code**	**Description**
LOW	Green	Installation is considered to have an acceptable financial exposure value.
MEDIUM	Amber	Installation is considered to have a financial exposure value that is above normal.
HIGH	Red	Installation is considered to have an unacceptable financial exposure. Assuming that the traffic light limits have been sensibly set, then the 'High' status can be attributed to unusually high meter biases and/or high random uncertainty in the installation Fiscal meter and/or one of its child field meters.
NO RESULT	Blue	A 'No Result' status can be returned due to a number of factors; however the most likely causes are, invalid mapping of the actual label to its data source or undefined traffic light limits.

3.1.2 Main GUI

The main GUI shown in Fig. 2 provides the user with an interface for modifying and viewing detailed installation and field related information. This includes modification and viewing of associated fiscal and field meter attributes via detected forms.

The information on the main GUI represents the information for one single installation and its associated child fields.
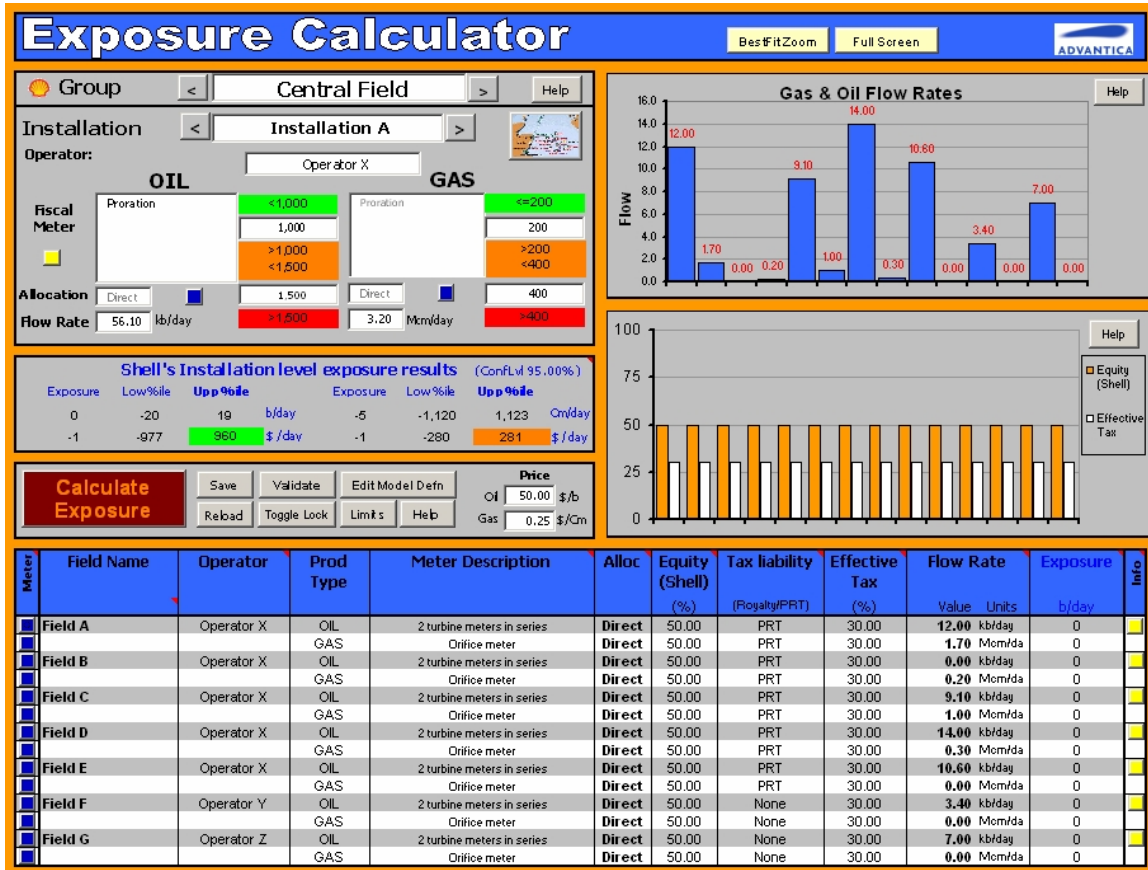

Fig. 2 – Screen shot of the main GUI

Alternatively the user can scroll by installation group. The (blue) command buttons to the left of each field name, when clicked, launches a meter form where the user can modify various parameters that define a given meter's accuracy and precision. Also the (yellow) command buttons at the far right of the same field table allows the user to view general descriptive text about a given field. These types of buttons are also present for each gas and oil installation.

4   EXPOSURE MODEL OVERVIEW

Fig. 3 shows a partial domain model highlighting the important items. This figure gives a visual representation of the real-world objects and concepts of interest. Also see Fig. 6 (page 8) that also illustrates the connectivity for a typical installation and its associated fields.
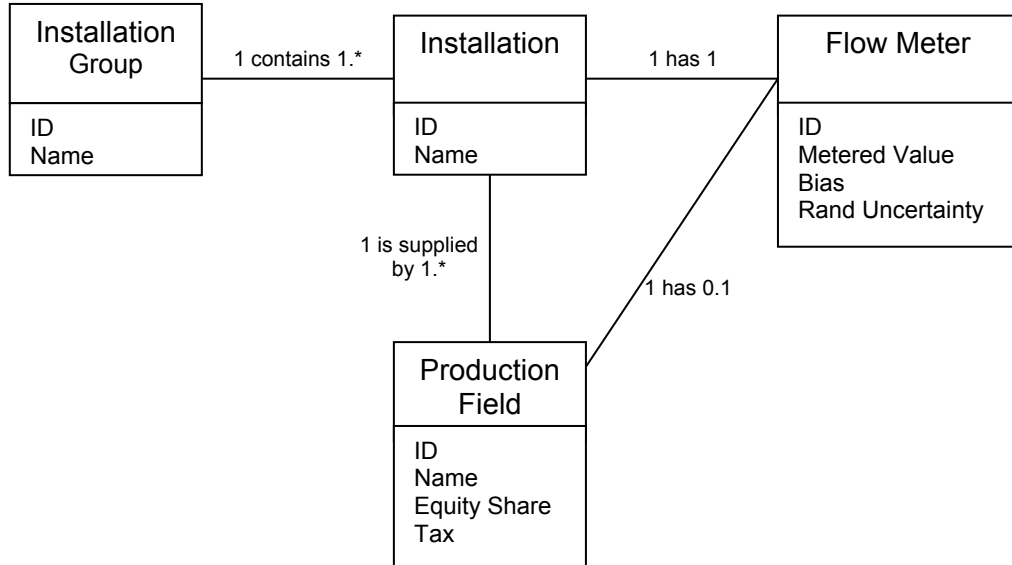
Fig. 3 – Partial Domain Model

Note, since we are not concerned with the actual transportation effects of oil or gas then the real-world pipes have been excluded from Fig. 3. Readers familiar with UML[1] can see that the model also describes the multiplicity between various domain objects. For example, an installation must have at least one child field, which in turn can have either one flow meter or none.

4.1   Meter uncertainty

There are two basic elements in defining the overall uncertainty for a generic meter, namely its accuracy and its precision.

4.2   Meter accuracy

The accuracy of a meter is usually expressed in terms of a bias value, which may have a constant (offset) component and or a flow proportional component (allowing the metered value to drift from the true value as the flow rate changes). A positive bias means that the meter is overstating (over reading) the true value; conversely a negative bias means that the meter is under reading. A meter may be calibrated against some standard so that any bias is reduced to zero (or very near to zero for a given operating range) thus giving an accurate meter.   In practise there will always be some random uncertainty associated with the calibration process itself partially due to the fact that the true value (for this standard) can never be precisely known. This random uncertainty in the calibration process is not modelled.

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[1] The UML (Unified Modelling Language) is a standard diagramming notation.

4.3   Meter precision

The precision of a meter is a measure of the random uncertainty associated with the meter result (or reading). If a meter were to be read many times under the same conditions[2] and the readings were to be varied, then the meter would be classed as being imprecise, conversely if the readings were very similar then the meter would be regarded as precise. In reality there are many factors that contribute to the random uncertainty for a particular meter measurement and there are a number of ways that this uncertainty can be expressed. A common format is to state the measured value M together with a quoted uncertainty k as $M \pm k$. The exposure tool allows an additional flow rate dependent uncertainty component to be defined so that the total meter uncertainty (due to random effects) can be modelled as $M \pm (k + Me)$ with an associated normal distribution and a user definable confidence level (Usually 95%) where e is a fraction term. Fig. 4 shows the layout of the meter error definition form from the Exposure Tool.

Fig. 4 – Meter error definition form layout (normal distribution)

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[2] This is a hypothetical scenario, which cannot be achieved in practise.

The tool also allows the modelling of non-symmetric error distributions (currently by means of a triangular distribution). In this case we have the flexibility to define the uncertainty range for a given meter in the following manner.

$$M - (k_{Lower} + Me_{Lower}) \leq M \leq M + (k_{Upper} + Me_{Upper})$$

Fig. 5 shows the meter error definition form layout for a triangular distribution. Note since the parameters have been set so that $e_{Lower} \neq e_{Upper}$, then the triangular distribution is skewed for non-zero metered flows.

Fig. 5 – Meter error definition form layout (triangular distribution)

5 EXPOSURE MODEL - MATHEMATICAL DETAIL

Fig. 6 illustrates the general problem domain in which there is a tree network of n metered[3] pipes each with a metered flow rate value M_i and an unknown true value of P_i. Each of these pipes leads from a separate[4] production field and joins a main export pipeline, which is directly metered by a fiscal meter[5]. The fiscal meter has a metered flow rate value M_F and an unknown true value of P_F.
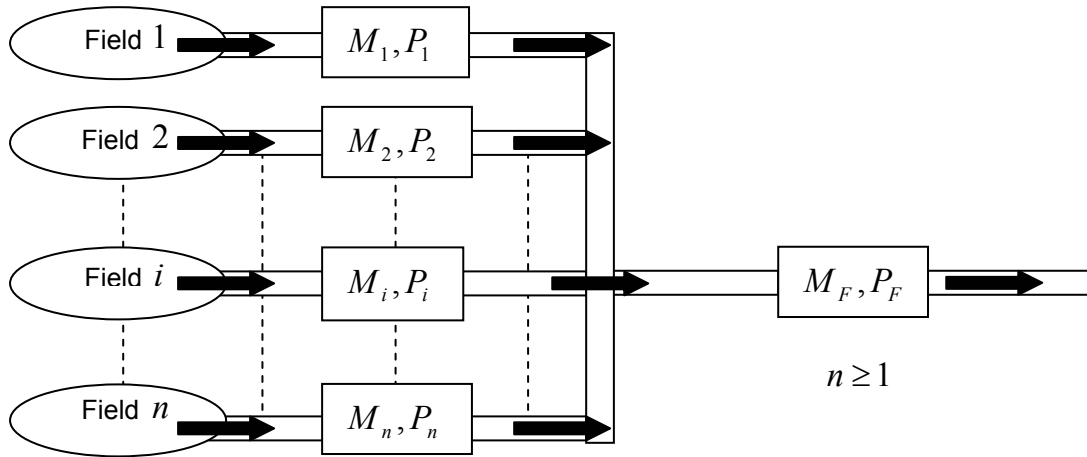

Fig. 6 – Generic Problem Domain

For any meter the metered flow rate value M is related to the unknown true value P by the following equation,

$$M = P + B + U \qquad \text{(Eq. 5-1)}$$

Where,

B is the known or estimated meter bias (offset).

U is the random flow rate measurement uncertainty.

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[3] The model is modified later to deal with the case in which one of these pipes is not directly measured.
[4] The fact that each pipe leads from a *separate* production field is not a strict requirement.
[5] The metered value given by the fiscal meter is used as a basis for financial billings.

5.1 Meter Bias

From Eq 5-1 we can see that if the meter bias is positive then the meter is over stating the true value and if it is negative, it is understating the true value.

For a perfectly calibrated meter, $B = 0$. i.e. the meter is unbiased[6], also there would be no random uncertainty associated with the zero bias value[7].

For the purposes of this model, only the meter accuracy is modelled - not it's precision. This means that there is no associated distribution profile for the meter bias value.

The meter bias B is assumed to be some function of the metered flow rate, i.e. $B = f(M)$. If we believe that the meter is offset by a constant amount c plus a flow dependant amount MK, then we may express the total absolute bias as

$$B(M) = c + M\frac{K}{100}$$

(Eq. 5-2)

Where c is a constant bias term with units of flow rate and K is a percentage bias term. Eq. 5-2 allows us to model the bias as constantly offset and/or drifting as the flow changes.

5.2 Meter uncertainty

In general the random uncertainty of the true product flow can be expressed as a zero mean, random component U, which is taken (or sampled) from a defined probability density function (pdf) D that has characteristic parameters $\{a_1...a_m\}$.

$$U \sim D\{a_1...a_m\}$$

For a normal distribution we may write $U \sim N\{\sigma\}$, where σ is the standard deviation.

It is common practise but not mandatory to express random uncertainty at the highest level in terms of a standard deviation parameter as described above. An equivalent alternative is to define a range of values that the true value is believed to lie within (for example $\pm 2\%$ of the metered value). If a normal probability distribution type is assumed for this range of values and there is stated confidence level then we have sufficient information to derive an associated standard deviation value for this pdf. This will allow random values to be sampled in the usual way.

The first step is to choose a confidence level γ (say 0.95 for a 95% confidence). From this T can be calculated. For $\gamma = 0.95$, T would be ~1.96.

$$T \sim NormSInv(1 + \gamma)/2$$

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[6] Unbiased means the meter is accurate and does not drift.
[7] Zero random uncertainty means the meter is perfectly precise so that repeated measurements of the same value under the same conditions would give identical results.

NormSInv is a VBA function that returns T, the inverse of the standard normal cumulative distribution. Given a user defined symmetric half width range equal to $\pm(k + Me)$,

with centre value M (which is the metered flow value),

where k is a constant and e is a percentage value[8].

The standard deviation σ can easily be calculated using the following equation

$$\sigma = \left(k + M\frac{e}{100}\right)/T$$

5.3   Field Exposure

The non-monetary exposure for field meter i due to meter inaccuracies and imprecision is given by the difference between the estimated true product flow P_i and the measured product flow M_i. i.e.

$$Exposure_{Field(i)} = P_i - M_i \qquad\qquad\text{(Eq. 5-3)}$$

Rearranging Eq. 5-1 for P and substituting into Eq. 5-3 gives

$$
\begin{aligned}
&= \{M_i - B_i(M_i) - U_i(D_i)\} - M_i\\
&= -\{B_i(M_i) + U_i(D_i)\}
\end{aligned}
$$

The negative sign convention means that a loss is made if the exposure is positive.

5.4   Installation Exposure

The non-monetary exposure for an installation with n fields is given by

$$Exposure_{Installation} = \sum_{i=1}^{n} S_i\left(P_i - \frac{M_i P_F}{\sum_{k=1}^{n} M_k}\right) \qquad\qquad\text{(Eq. 5-4)}$$

where $S_i = Q_i(1 - T_i)$ which is Shell's post tax equity share in field i,

Q_i - Shell's equity share (i.e. percentage take of production)

T_i - Taxation rate.

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[8] Shell define *e* as the exposure factor which can be derived from *e=A*U* where *A* is the audit factor and *U* is the nominal measurement uncertainty.

Note that the term $\dfrac{M_i P_F}{\displaystyle\sum_{k=1}^{n} M_k}$ in Eq. 5-4 represents the metered error proportion for field i.

Also $\displaystyle\sum_{k=1}^{n} M_k$ is the metered field flow sums and must be non zero since it used in the denominator of Eq. 5-4.

Again rearranging Eq. 5-1 for P and now substituting into Eq. 5-4 gives

$$= \sum_{i=1}^{n} S_i \left\{ \left(M_i - B_i(M_i) - U_i(D_i) \right) - \left(\frac{M_i \left(M_F - B_F(M_F) - U_F(D_F) \right)}{\displaystyle\sum_{k=1}^{n} M_k} \right) \right\}$$

Finally, substituting Eq. 5-2 into the above gives

$$= \sum_{i=1}^{n} S_i \left\{ \left(M_i - \left(c_i + M_i \frac{K_i}{100} \right) - U_i(D_i) \right) - \left(\frac{M_i \left(M_F - \left(c_F + M_F \frac{K_F}{100} \right) - U_F(D_F) \right)}{\displaystyle\sum_{k=1}^{n} M_k} \right) \right\}$$

(Eq. 5-5)

5.5   By Difference Model

A minor variation is the case in which one of fields I is not metered. It is useful at this stage to introduce the notion of a virtual meter. In this case the flow value for this virtual meter is inferred by difference, i.e.

$$M_I = M_F - \sum_{i=1}^{n} M_i$$

By the rule of error propagation, the associated uncertainty for this meter is simply given by

$$U_I = U_F - \sum_{i=1}^{n} U_i$$

As expected the introduction of a virtual field meter increases the overall exposure at an installation level since we effectively have less information about the field flows.

5.6   Monte Carlo Simulation

By introducing small perturbations in Eq. 5-5, (i.e. randomly varying U_i, U_F according to their probability distributions D_i and D_F), the exposure value can be evaluated. If this is repeated many times (~10,000) an output distribution for the exposure value is produced.
The upper percentiles of this output distribution are used to give a value that when multiplied by the unit production price gives a likely monetary loss (or gain if the value is negative) made by Shell as a result of meter uncertainties.

6   CONCLUSIONS

- Modelling of financial exposure due to meter uncertainties helps a shipper to make informed business decisions with regard to the likely monetary loss (or gain) at key fiscal Installation and field nodes.

- The developed prototype tool allows financial exposure levels to be easily estimated and monitored.

- With the two levels of data displays, engineers and operators can use the tool with ease. As long as the source data is set under password protected entry and as such deemed to be representative, the output values can be utilised by all.

- The tool is useful at the design phase of a project. By manipulation of the inputs the user can determine the optimum specification needed to meet the requirements defined in the licence to operate at relevant operating agreements. This allows decisions to be taken on the balance of the cost of the new system against the exposures.

- The approach taken with the new tool utilises both static and dynamic data to determine present exposure. This is arguably more relevant than a one off static uncertainty calculation at the build phase of a new system, which is never then consequently updated.

7   RECOMMENDATIONS

- The tool is an initial approach to giving a better understanding of the status of the systems and nodes within the system. It can be developed further by looking at operations and maintenance aspects in more depth – such as performance across the installation and predictive frequency determination.

- Inclusions of a standard analytical approach (as well as Monte Carlo) to derive financial exposures in cases where all meter uncertainties have a 'normal' profile.

- Migration/redevelopment of tool to a more scalable and manageable VB and Access solution rather than VBA.

- Incorporation of import macro's allowing bulk updates of meter flow rates and other simulation attributes would enhance the input data process, thereby keeping derived exposure calculations valid (by moving from a static status to a more preferred dynamic representation of the modelled system).

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.