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A new methodology for cost-benefit-risk analysis of oil metering station lay-outs

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ABSTRACT

Custody transfer oil metering stations are traditionally equipped with spare meter runs and proving device with on-site calibration possibilities for the proving device. Such a layout is expensive (CAPEX and OPEX). The gain is that metering uncertainty is low to secure national and company income.

Currently, there is major focus on cost-reduction in the oil industry. This has initiated increased focus on metering station costs, and increased need for cost-benefit analysis for proposed metering station layout. Such analysis traditionally address balance between investment, operational costs and uncertainty.

Simplified metering stations may have larger measurement uncertainty than more complex stations. In addition, if a flow meter or other essential components fail, the metering station uncertainty may increase significantly in the period before repair or replacement. For metering stations with simpler layout it may also be more time consuming to take repairing actions, due to lack of access. All this increases the risk of loss of income from the exported oil.

The methodology proposed in this paper combines situations when flow meters are malfunctioning and when they are working. Response times for repair are included. Probabilities of the different states (functioning, malfunction, etc.) are derived using steady state Markov models. Total risk due to normal and increased uncertainty over a metering station life time can then be calculated.

Several metering station layouts, from complex to simple, are analysed using the new proposed method, where the risk of loss due to normal and increased uncertainty is combined with CAPEX and OPEX to identify optimal metering station layout with respect to risk of loss of income for a given field.

The new method enables the derivation of the overall risk associated with the malfunction of one or several flow meters in a metering station. Enhanced cost-benefit analysis with this additional risk are presented, for a series of metering station layouts.

1 INTRODUCTION

The aim of this paper is present a new methodology to show how the risk associated with different solutions for the fiscal measurement of oil flow can be calculated. Risk is here the risk of loss of income from the deviation between the actual amount and the measured amount of oil or gas, or the risk of loss during production shut-down. Furthermore, a cost-benefit analysis combining the risk and cost (CAPEX + OPEX) of each metering configuration is presented. Quantifying risk and comparing it to fixed costs can be an informative contribution in the process of choosing between different metering station solutions.

In order to establish a quantitative estimate of the probability, consequence and thus risk associated with the different states or conditions that the metering station may be in, the following input parameters must be provided to the model:

- Flow rate of metering station
- Oil price
- Measurement uncertainties associated with the different metering configurations
- Mean time to repair (MTTR) a meter
- The expected time between planned production stops
- The mean time to failure (MTTF) of a meter
- Operating hours per year of a meter
- Number of years the analysis should cover
- Expected life cycle costs for the different metering configurations

These parameters do not have any definitive, "correct" value, and may vary from project to project. In this paper, we have studied the risk associated with different metering configurations based on an example set of these input parameters.

The first part of this paper explains the method used for the risk analysis. Then we calculate the probabilities of the metering stations being in different states depending on whether the individual meters function or fail. We continue by estimating the consequences of being in these different states. Then we calculate the risks associated with each of the states using the formula: $Risk = Probability \cdot Consequence$. In the end, we compare the overall risk with the CAPEX and OPEX costs associated with the different metering configurations.

2 DESCRIPTION OF DIFFERENT METERING STATION CONFIGURATIONS

The risk and cost-benefit study is carried out for six different fiscal oil metering station configurations, ranging from a conventional solution to more simplified solutions.

The following nomenclature is used:

- DM: Duty Meter
- PD: Prover Device
- CP: Compact Prover
- MM: Master Meter

2.1 Configuration 1: Conventional system with prover device

Figure 1 shows a traditional solution with inline calibration using a large volume prover (typically used every 4th day) and a backup run for the DM. If both DM fail, the production is shut down. If one DM fails, there is enough capacity in the other DM, and production can continue without increased uncertainty in the flow metering. The failed DM can then be replaced or repaired without waiting for the next planned production stop, as it is placed in a parallel run.

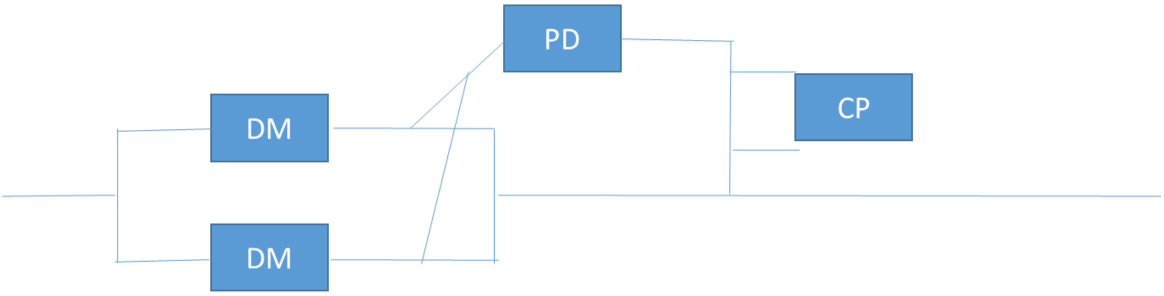

Figure 1: *Configuration 1, conventional solution with a prover device for proving.*

2.2 Configuration 2: Conventional system with master meter

Figure 2 shows a modified configuration of the conventional metering station configuration, with parallel runs (one duty run and one backup run). This configuration has inline calibration in a bypass loop using a master meter with a yearly connection of a compact prover. This configuration is expected to have a slightly higher uncertainty than configuration 1, as the inline calibration is performed with a master meter instead of a prover device.

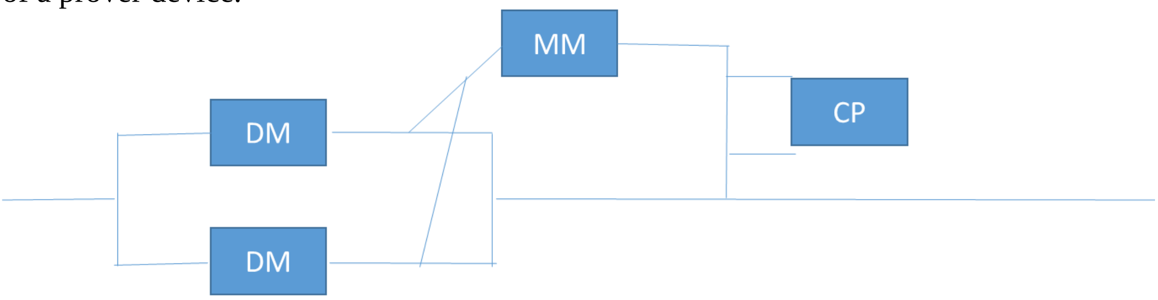

Figure 2: *Configuration 2, use of a master meter for proving instead of a prover device.*

2.3 Configuration 3: Simplified solution with master meter bypass

Configuration 3 consists of one duty meter in a single run, with inline calibration using a master meter in a bypass loop (typically used every 4th day) with possibility of a yearly connection of a compact prover. In normal operation configuration 3 has comparable uncertainty to configurations 1 and 2 with only one DM operational. The risk is higher for configuration 3 as there is no bypass loop around the DM. Hence, if the DM fails one has to wait for a planned production stop for repair. There will be an increased uncertainty of the metering station in this period, as the MM will be used as a DM.

For this metering station configuration, the MM can be changed or repaired independent of production pause.

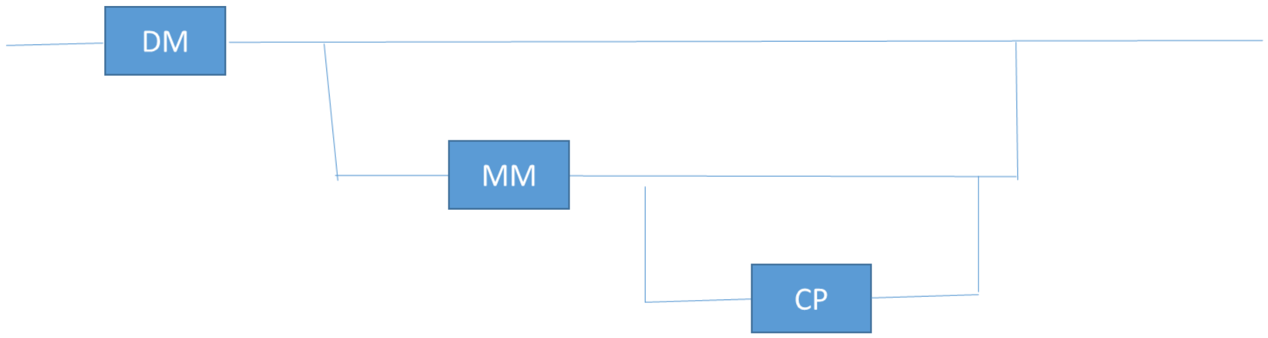

Figure 3: *Configuration 3, with DM in a single run and a bypass loop with a MM.*

2.4 Configuration 4: Simplified solution with master meter inline

Configuration 4 consists of one single run with inline calibration using a master meter, with a compact prover bypass loop for yearly calibration. The risk for this configuration is higher compared to the previous configurations, since the master meter cannot be disconnected and maintained during operation.

There is no bypass loop around the DM nor the MM. Hence, if the DM or MM fail, one has to wait for a planned production stop for repair. There will be an increased uncertainty in this period.

The differences between configuration 3 and configuration 4 are:

- The MM in configuration 3 is protected from daily wear and tear, whereas the MM in configuration 4 is subject to daily wear and tear, as well as scale build-up etc.
- In configuration 4 it is only possible to do a comparison between the MM and the DM and compare the deviation between the measured values. This is not considered to be a normal calibration.

Figure 4: *Configuration 4, with DM and MM in the same single run.*

2.5 Configuration 5: Simplified solution with MM inline and no CP

Configuration 5 is a simplified configuration with one single run with inline calibration using a MM, and no compact prover. The risk for this configuration is comparable to configuration 4, since the master meter cannot be disconnected and maintained during operation.

The difference from configuration 4 is that configuration 5 has no onsite calibration possibility for the master meter, and that offsite calibration may only be performed during planned production stops. This increases the uncertainties of the meters compared to configuration 4.

Figure 5: *Configuration 5, only a DM and a MM, no bypass loop for a compact prover.*

2.6 Configuration 6: Simplest configuration with one duty meter and no on-site proving possibility

Configuration 6 is the simplest configuration possible, with a single run with only one duty meter, no master meter and no compact prover. Calibration of the duty meter has to be performed offline. This metering station thus has a higher uncertainty compared to the previous configurations, and the probability of a production shut down is higher as there is only one meter. As expected, this configuration represents the highest risk.

Figure 6: *Configuration 6, a single run with only one duty meter, no master meter and no compact prover.*

3 METHOD FOR RISK ANALYSIS

Based upon the six different configurations outlined in section 2, we develop a steady state Markov model for the problem. A metering station may be in different states i depending on the functioning of the different individual meters. For each of the metering station configurations studied in this paper, we have calculated the probability P_i of being in each of these states i. Then we have established the consequence Q_i of each state. The consequence Q_i has been limited to either the potential loss of revenue by mis-allocation due to measurement uncertainties, or the potential loss associated with production shut-down.

Then the overall risk R_i for each state i is calculated using: $Risk = Probability \cdot Consequence$:

$$R_i = P_i \cdot Q_i$$

The risk associated with a system that has N possible states, is then expressed as the statistical expected loss, using the following equation [1, p. 7]

$$R_{total} = \sum_{i=1}^{N} R_i = \sum_{i=1}^{N} P_i \cdot Q_i$$

In this analysis, we assume that depending on their complexity, the metering stations could be in the following different states:

- Normal operation
- Failure of duty meter (DM)
- Failure of master meter (MM) or prover device (PD)
- Failure of all meters

4 PROBABILITY OF DIFFERENT STATES

In order to set up the risk-budget, it is necessary to estimate the probabilities for all the different combinations that are possible for each metering station.

4.1 Input parameters to the probability calculations

Input parameters for calculating the probability distribution of the different scenarios are described in the following. Note that the example values that are assigned to each of the parameters here are only examples. When the method is used to evaluate a specific project, these parameters must be thoroughly determined. The goal of this paper is **not** to estimate these parameters in detail, but to demonstrate the use of a new framework for risk-calculation.

T - Operating duration

T is the operating duration in hours, for which the probability is calculated. The operating duration depends on how the meter is placed in the metering station.

- *Main run:* For a meter in the main run, it is assumed that the meter is in operation 100 % of the time, and $T_{main\ run}$ is typically set to 8760 hours times the number of year for the analysis.
- *Bypass loop:* If the meter is situated in a bypass loop, the operational duration is much lower than for a meter situated in the main run. For a meter that is situated in a bypass loop, T_{bypass} depends on how frequently the proving is performed, and for how long periods of time. If, for example, the proving is performed every 4th day, with a duration of 1 hour each time, then T_{bypass} is only a small fraction of $T_{main\ run}$.
  In reality, the meter components may degrade with time, even if the meter is not in operation. Thus, it is necessary to include this passive degradation in the

calculation of probability of failure. This may be done by assuming that the passive degradation is proportional to the actual time that passes, and that for example every four days that passes when the meter is passive, result in comparable degradation as 1 day in operation. This can be simplified and implemented by dividing the operation time of the metering station by 4, so that $T_{bypass} = \frac{T_{main\ run}}{4}$. Note that this is just an assumption that is used in the example calculations shown.

λ - Failure rate

The failure rate λ is inversely proportional to the mean time to failure (*MTTF*) for the meter in operation, expressed in hours. It is important to notice that we here assume that the meter has not exceeded the expected service lifetime, and that it is used during the normal operating period where the failure rate can be assumed to be constant. It is possible that the *MTTF* may increase directly after installation due to possible adjustment problems[1], or at the end of the expected service lifetime due to wear and tear. For simplicity, the *MTTF* used in this analysis is assumed to be constant and cover failures in other critical components (temperature transmitters, pressure transmitters, and densitometer, as well as valves etc.) associated with the meter in question. The *MTTF* is in the examples shown here assumed to be in the order of 4 years of operation, but this is just an example value and must be determined for each specific meter.

μ – Repair rate

μ is a parameter that is inversely proportional to the mean time to repair (*MTTR*), the expected time to repair the meter, in hours. *MTTR* depends on how the meter is placed in the metering station.

- *Main run – wait before repairing :* If the meter is placed in the main run, with no possibility of bypass, it is assumed that one has to wait until the next planned production stop in order to repair the meter. If it is assumed as an example that there will be a planned production stop every 5 years, the mean time to repair could be estimated to be half of this period, and μ_W is set to $\frac{1}{2.5\ years \cdot 365\ days \cdot 24\ hours}$ in the example calculations in this paper.
- *Bypass loop – direct repair possible:* If it is possible to disconnect the meter and repair it, without stopping the production, it can be assumed as an example here that the meter will be repaired or replaced during 48 h. μ_D is therefore set to $\frac{1}{48\ hours}$ in the example calculations in this paper.

4.2 Probability of a dependent system in different states - Steady state probabilities from a Markov model

If a system only consists of components where the probability for one component being in a failure or function state is independent of the state of the other components, it is straightforward to find the probabilities of the overall state of the system by multiplying together the probabilities of the individual components being in the different states.

[1] As fiscal oil flow meters are expected to be sufficiently calibrated onshore before installation this may not be applicable in this case.

If, on the other hand, the state of an individual component is dependent on the state of one or several of the other components, as is the case for the metering station configurations studied in this report, then the correlation between the probabilities must be taken into account. An example is the dependence of the DM and the MM in configurations 4 and 5. If only one of the meters is in a failure state, it is assumed that the meter will not be changed/repaired before the next planned production shut down. However, if the meters are in a failure state at the same time, it is assumed that the production will be shut down directly and that the meters will be repaired/replaced within hours.

[1, p. Appendix D.4] outlines a method for taking this interdependence between the individual meters of the metering station into account. This method is based on Markov models, assuming that in the long run, the rate of arrivals into a specific state will equal the rate of departures from that state. Figure 7 shows a diagram with the different states a system consisting of one DM and one MM can be in, and the transition rates between the different states. Here λ is the failure rate and μ_W is the repair rate waiting for a planned production stop before repairing, and μ_D is the repair rate when both meters are in a failed state at the same time and will be repaired directly.

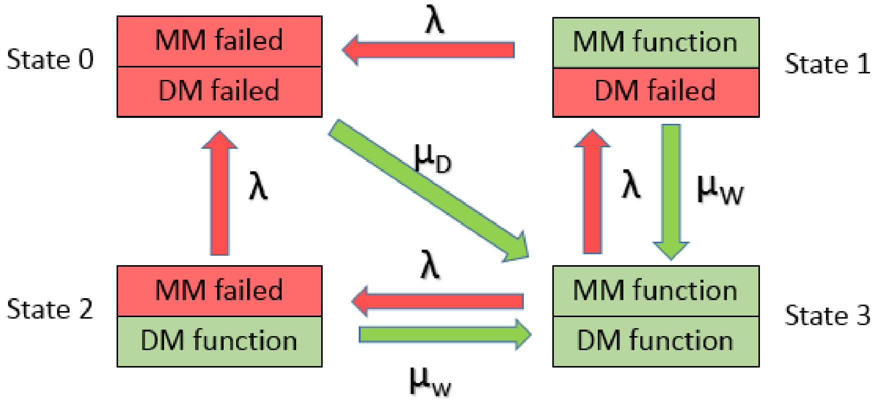

Figure 7: *Markov model for a DM and MM in series (configuration 4 and 5).*

Table 4-1: *State / probability budget for a DM and MM in series (configuration 4 and 5).*

	Departures	**Arrivals**
State 0	$P_0 \cdot \mu_D$	$(P_1 + P_2) \cdot \lambda$
State 1	$P_1(\lambda + \mu_W)$	$P_3 \cdot \lambda$
State 2	$P_2(\lambda + \mu_W)$	$P_3 \cdot \lambda$
State 3	$2P_3 \cdot \lambda$	$(P_1 + P_2) \cdot \mu_W + P_0 \cdot \mu_D$

Table 4-1 shows a budget of probability times failure and repair rates for the expected departures from and arrivals to each state. This forms a set of linear equations, and together with the fact that the sum of all four probabilities must equal 1, it is possible to solve the set of equations and find the expected long term probabilities.

This method does not take into account any exponentially distributed probabilities of failure, as it is only the long term, steady state probability. In the special case where a meter is assumed to be repaired or replaced during every planned production shut down, and it can be assumed that the probability of failure increases exponentially with time, this may result in a slight overestimation of the probability of shut down in the first few years after such a replacement or repair[2].

The probabilities for the different states for the other configurations are calculated using the same method.

5 CONSEQUENCES ASSOCIATED WITH DIFFERENT SITUATIONS

5.1 Consequence associated with metering uncertainty

The potential loss associated with metering station uncertainty can be expressed in terms of the expanded uncertainty using the following equation based on Stockton [2]:

$$Q = potential\ loss = \frac{U^* \cdot NPV}{\sqrt{8\pi}} \approx 0.2\ \cdot U^*\ \cdot NPV \qquad (5.1)$$

Here U^* is the relative expanded uncertainty (2 standard deviations, 95 % confidence level) associated with the measurement of the flow, and *NPV* is the net present value of the oil. The factor $\frac{1}{\sqrt{8\pi}}$ comes from the integration from -∞ to 0 of the assumed normal or Gaussian uncertainty distribution.

The relative uncertainty U^* used in Equation (5.1) depends on the configuration of the metering station.

Table 5-1 gives an overview of uncertainties for the meters in the different metering station configurations, which are used in the analysis in this report. Note however, that these are estimated uncertainties based on experience with similar systems. A more thorough, project-specific analysis would be needed in order to establish these uncertainties for a specific case. For cases with high water fraction and/or non-homogenous flow, as well as for metering stations with gas break out due to pressure loss, the uncertainties used here may be underestimated.

[2] It is possible to include this time-dependent nature of the probabilities of failure by stating that the arrivals to and departures from a state *i* equals the derivative of this state's probability, P_i'. This would result in a system with linearly interdependent differential equations that may be solved using the Laplace Transformation of the system or by finding the eigenvalues of the system matrix. This is a more exhausting operation, and is subject to further work.

Table 5-1: *Overview of uncertainties for the meters in the different metering station configurations denoted V1 to V6 (relative expanded uncertainty* $\boldsymbol{U^*}$ *at 95 % confidence level). These are estimated example uncertainties based on experience with similar system, and must be updated specifically for each case.*

Metering station	**Meter**	$\boldsymbol{U^*}$ **(95 % c.l.)**	**Comments**
V1	DM	0.25	Duty meter proved with prover device in bypass
V2	DM	0.30	Duty meter proved with master meter in bypass
V3	DM	0.30	Duty meter proved with master meter in bypass
	MM	0.50	Master meter with bypass calibration possibility
V4	DM	0.40	Duty meter proved with master meter inline
	MM	1.00	Master meter inline
V5	DM	0.60	Duty meter prover with inline master meter, without CP
	MM	1.50	Master meter inline, without CP
V6	DM	1.00	Duty meter without proving or calibration
All stations	DM	1.00	Duty meter without proving or calibration

5.2 Consequence associated with failure of all meters

There is a probability that several meters will fail in the metering station. If it is no longer possible to measure the flow, the failure of the meters may result in a shutdown of the metering station, during the time period of which the meters are repaired. The cost or consequence of a shutdown is in this study for simplicity taken as the lost cash flow due to lost production during the time to repair. Another way of calculating the cost associated with a shut-down is to calculate the present value loss, which is the cost of delaying the production.

$$Q_{all\ meters\ fail} = NPV \tag{5.2}$$

However, in some special cases, it may be possible that the production should not be shut down, but that the flow should be estimated from other metering points or from performance curves, history etc. In such cases, it is possible to define the uncertainty U^*_{NM} that may for example be in the range of 50 % and above. In this special case, the consequence of a “no measurement” situation is the following:

$$Q_{all\ meters\ fail} = 0.2 \cdot U^*_{NM} \cdot NPV \tag{5.3}$$

6 RISK ASSOCIATED WITH DIFFERENT SITUATIONS

As explained in chapter 2, the risk is calculated as the product of the probability of a state and the consequence or potential loss associated with this state. For configuration 5, which was taken as an example in chapter 4, the risks are the following:

$$\begin{gathered} R_0 = P_0 \cdot Q_0 = P_0 \cdot NPV \\ R_1 = R_2 = P_1 \cdot Q_1 = P_2 \cdot Q_2 = P_1 \cdot 0.2 \cdot U^*_{\text{DM inline MM,no CP}} \cdot NPV \\ R_3 = P_3 \cdot Q_3 = P_3 \cdot 0.2 \cdot U^*_{\text{MM inline,no CP}} \cdot NPV \end{gathered} \quad (6.1)$$

All parameters are defined in section 4.2 and 5.

The total risk associated with configuration 5, related to the functioning of the meters and their uncertainty, is thus:

$$R_{Total,config.5} = R_0 + R_1 + R_2 + R_3 \quad (6.2)$$

6.1 Discussion of results of risk analysis

Figure 8 shows a comparison between the risks associated with the different metering stations, for an example set of input parameters.

As expected, the risk increases from metering station configuration 1 to configuration 6.

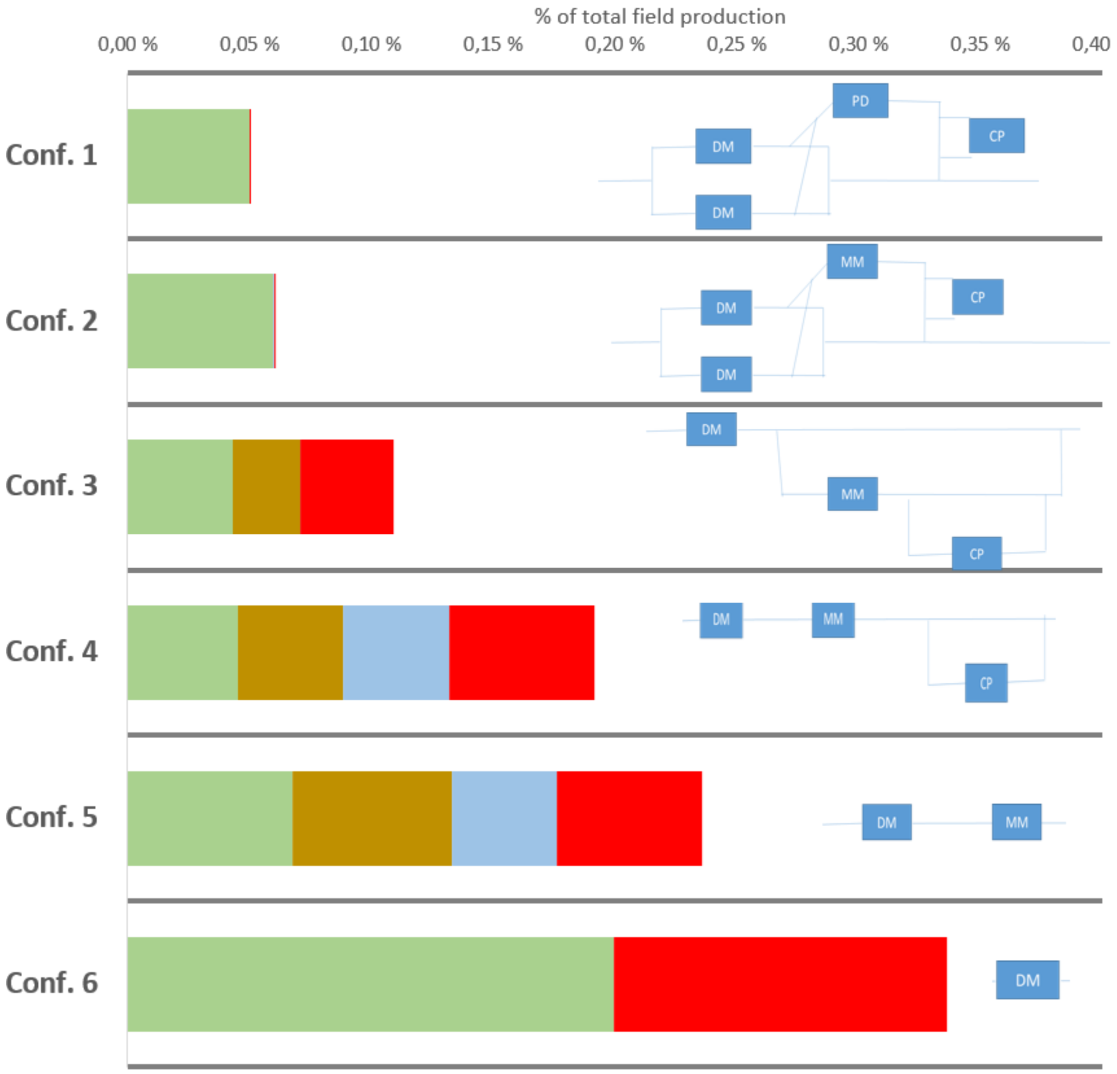

Figure 8*: Example comparison between risks associated with different metering configurations. The green parts represent risk associated with normal operation, the yellow/brown parts the risk associated with failure of one DM, the blue parts the risk associated with MM or PD failure, and the red parts the risk associated with shut down of production.*

The following conclusions can be drawn from the results shown in Figure 8:

- **The risk associated with normal operation** increases from configuration 1 to configuration 6:
  - The DMs in configuration 1 are proved regularly with a prover device, which again is calibrated annually against a compact prover.
  - The DMs in configuration 2 are proved regularly with a master meter, which again is calibrated annually with a compact prover. The use of a master meter instead of a prover device results in a small increase in the normal operation uncertainty and consequently in the associated risk.
  - The DM in configuration 3 is proved and calibrated in the same manner as the DMs in configuration 2, but as there is only one DM in configuration 3, if this fails the metering station is no longer in normal

operation. Therefore the probability that the metering station is in a normal operating state, and thus the risk associated with this state, is lower for configuration 3 than for configuration 2.
  - The DM in configuration 4 is proved against a MM that is inline, and more subject to wear and tear than for a MM in a bypass loop. This results in a higher uncertainty during normal operation, but the probability of being in the normal state is lower for configuration 4 than configuration 3. The combination of probability and consequence results in a slightly higher risk for configuration 4 compared to configuration 3.
  - The DM in configuration 5 is only proved against a MM that is not regularly calibrated. This results in a higher uncertainty during normal operation, and thus a higher risk during normal operation compared to configuration 4.
  - The DM in configuration 6 is not regularly proved. The higher uncertainty associated with this metering configuration results in a higher risk during normal operation.

- **The risk associated with a failure of one DM** is negligible in configuration 1 and configuration 2, as there are two DMs here, and if one of them fails, the other should be able to measure the flow without increased uncertainty. For configurations 3 to 5, there is a potential loss associated with a DM failure, as the flow then has to be measured by the MM, with increased uncertainty. For configuration 3, with a MM in a bypass loop the increase in uncertainty is less than for configuration 4 where the MM is placed in line, and the uncertainty is highest for configuration 5 where the MM is inline and has no possibility of regular calibration.

- **The risk associated with a failure of the MM or PD**: Even if the potential loss associated with a failure of the MM or PD is identical for configurations 1 to 5, the probability of this situation is considered to be minor for configurations 1 to 3, and higher for configurations 4 and 5. This is because when the MM or PD are in a bypass loop, they can be changed /repaired directly, without having to wait for the next planned production shut down. For configurations 4 and 5, the MM is in line with the DM in the main run. The period from the failure happens to the meter is replaced/repaired is thus longer. The probability of the situation with a failed meter in any chosen period is higher, and the risk associated with this is thus higher too. For configuration 6, this situation is not applicable.

- **The risk associated with a production shutdown** is much smaller for configurations 1 to 5 than for configuration 6. This is due to the fact that configurations 1 to 5 have to be shut down only if two meters fail at the same time, the two DMs for configurations 1 and 2, and the DM and the MM for configurations 3 to 5. For configuration 6, on the other hand, it is sufficient that the only meter present fails, and the probability for a shutdown is thus higher. The probability that the two meters are in a failed state simultaneously is lower for configurations 1 and 2 than for configurations 3-5. This is because the DM in configurations 3-5 is in-line, and the probability that it is a failed state is here higher, since we assume in this example that it will not be repaired before the next planned production stop.

7 COST-BENEFIT ANALYSIS

A cost-benefit analysis of a metering configuration takes into account all the costs associated with a metering solution, including installation and operation costs, the metering accuracy, functionality and reliability. Based on the combined risk and cost of each metering solution, it is then possible to do a qualified choice of which metering solution should be chosen for an application from a cost-benefit perspective.

7.1 Background information

According to Chan [3], the net present value for a metering option is usually analysed with the traditional cost-benefit analysis using the following equation[3]:

$$\frac{E \cdot NPV \cdot improvement\ of\ metering\ uncertainty[\%] \cdot R}{100\%} = max. CAPEX\ for\ the\ metering\ consept \tag{7.1}$$

Here E is the ownership factor (equals 1 if there is only one owner for the field), NPV[4] is the net present value and R is the risk factor ($R = 0.2$ is used in this analysis, ref. paragraph 5.1). The improvement of metering uncertainty using an alternative metering configuration is in this way compared with the maximum cost increase that should be associated with this alternative.

NORSOK I-106, Annex C [4], uses a similar[5] approach to compare two metering concepts A and B, using the following equation to decide if concept B may be acceptable[6]:

$$(C_A - C_B) > (U_B - U_A) \cdot R \cdot NPV \tag{7.2}$$

Here C_A and C_B denote the total life cycle costs for each concept, and U_A and U_B denote the uncertainties associated with each concept. This equation can be rearranged into the following in order to compare the total life cycle costs and risks associated with each metering concept:

$$(C_A + U_A \cdot R \cdot NPV) > (C_B + U_B \cdot R \cdot NPV) \tag{7.3}$$

[3] In [3], another equation is proposed to perform an allocation cost-benefit analysis between more than two owners. This is not the case in this paper.
[4] [3] uses the term "NVP".
[5] The main difference between the two approaches is that the NORSOK I-106 appendix C considers the total life cycle cost of the meters, whereas the GDF approach considers the CAPEX of the metering concepts.
[6] NORSOK I-106 proposes another equation when there are more than one owner. The risk of allocation with several owners is not the subject of this paper.

In addition NORSOK I-106 [4] states that the cost benefit analysis should also take into account the expected regularity of the possible concepts, and that a metering concept may be acceptable if:

$$\begin{aligned}&Reduction\ in\ profit\ by\ reduced\ regularity\\&\qquad < Reduction\ in\ profit\ by\ increased\ cost\end{aligned}$$

7.2 Cost-benefit analysis with quantified regularity and different metering station uncertainties

The methods presented in the previous section are useful when it comes to comparing two metering station concepts where the main difference is the risk associated with their metering uncertainty. However, it was found in chapter 5 and 0 that a metering station may have different metering uncertainties depending on which state it is in, and the risk associated with a potential shut down may be quantitatively included in the total risk associated with a metering concept.

The following formula is then established to calculate the total cost and risk associated with a metering concept:

$$Total\ cost\ and\ risk\ associated\ with\ a\ metering\ concept = C + R$$

$$C = total\ lifetime\ cost\ associated\ with\ a\ metering\ concept$$

$$R = R_{normal\ operation} + R_{increased\ uncertainty} + R_{shutdown}$$

In this simplified approach, the **total lifetime cost, $\boldsymbol{C}$,** includes the fixed costs that are not subject to risk or probability of failure:

- procurement and installation cost of the meter, including engineering resources and planning costs, as well as weight and dimension footprint at the platform (CAPEX)
- operational costs associated with planned maintenance, proving and calibration (OPEX)

The **risk term, $\boldsymbol{R}$,** includes the risks associated with the following (as found in chapter 5 and 0):

- risked exposure to lost revenue due to mis-allocation during
    - normal operation
    - periods with increased uncertainty as a result of failure of one or several meters
- production loss or delay during shut down, in the case where all meters that can be used for measuring production have failed

The total expected cost and risk calculated this way is then compared between the different metering solutions.

7.3 Total lifetime costs associated with each metering configuration

The total lifetime cost, C_j, includes the fixed costs that are not subject to risk or probability of failure. This cost may vary depending on the specific project due to differences in for instance oil properties, maximum expected flow rates, platform facilities and available resources. Furthermore, this cost may depend on the planning time of the metering solution, as the economical rates for material and resources may increase or decrease with time

In order to have a basis for a quantitative cost benefit analysis for this generic study, the total life cycle costs of configuration 1 (conventional solution) and configuration 5 (simplified solution) have been taken from Flølo [5]. The other configurations have then been assigned an expected total life cycle cost compared with configuration 1 and 5.

It is important to stress the fact that the main goal of this study is to establish a framework and a method for *comparing different* metering station configurations, and *not* to perform detailed calculations of the total lifetime cost associated with each configuration. The lifetime cost depends on the expected lifetime of the metering station, and it is possible that the numbers presented here are under- or overestimating a 10 year lifetime cost, which is used as an example. The following numbers are therefore only illustrative and the only reason that the numbers are quantified here is to illustrate the cost benefit analysis.

Configuration 1, conventional solution: According to the example in [5], a conventional offshore metering station may weigh approximately 100 tons, have a size of 15m x 5 m x 5m, a package cost of 5 million euros and a life cycle cost of 20 million euros, which roughly correspond to **160 million NOK**.

Configuration 2: According to an article from Faure Herman [6], the use of a master meter instead of a conventional proving device may reduce the overall cost of the metering skid with up to 40 %. The total life cycle cost associated with configuration 2 will therefore be set to 160 million NOK * 60 % **= 96 million NOK**.

Configuration 3: Since this configuration has only one DM and therefore only three meters, whereas configuration 2 has four meters, it is roughly estimated that the cost is proportional to the number of meters, and the cost of configuration 3 is therefore set to 96 million NOK * 75 % = **72 million NOK**.

Configuration 4: It may be assumed that the use of the MM in line with the DM instead of in a parallel run, may save space and weight and therefore result in a 20 % reduction in total life cycle cost compared with configuration 3. The cost of configuration 4 is therefore set to 72 million NOK * 80 % = **57,6 million NOK.**

Configuration 5, simplified solution: According to the example in [5], a simplified offshore metering station may weigh approximately 10 tons, have a size of 15m x 1 m x 1 m, a package cost of 1 million euros and a life cycle cost of 4 million euros, which roughly corresponds to **32 million NOK.**

Configuration 6: As this configuration has only one meter, compared with configuration 5 that has two meters, it may be expected that the total lifetime cost may be roughly divided by 2. The cost of configuration 6 is therefore set to 32 million NOK / 2 = **16 million NOK**.

8 DISCUSSION OF EXAMPLE RESULTS OF COST/BENEFIT ANALYSIS

Figure 9 and Figure 10 show graphically the results of cost and risk for each metering configuration, for two example cases. The examples show that higher risk is often associated with lower cost, as expected.

The optimal configuration(s) will depend on the input parameters of the specific case. The lifetime cost for each configuration, the production rate and the oil price are of particular importance in order to get a good cost benefit estimation. Other parameters as mean time to fail and to repair, metering station uncertainties and operating duration are equally important parameters that must be estimated specifically for each case.

The goal of this study is to show how a new framework can be used to include risk calculations related to increased uncertainty or shut-down in a cost-benefit budget, not to find a universally optimal metering station configuration.

It is important to note that it is not necessarily the configuration with the smallest sum of life cycle costs and risk that is the optimal choice, as this will also be dependent on acceptable risk contribution.

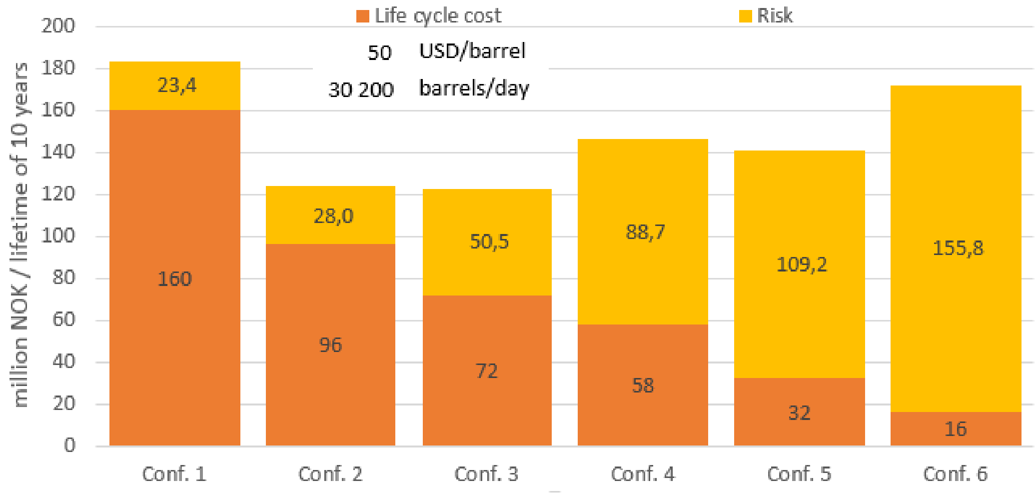

Figure 9: *Total life cycle cost and risk associated with each metering station configuration, in million NOK over a lifetime of 10 years. Example case with a production of 30 200 barrels/day.*

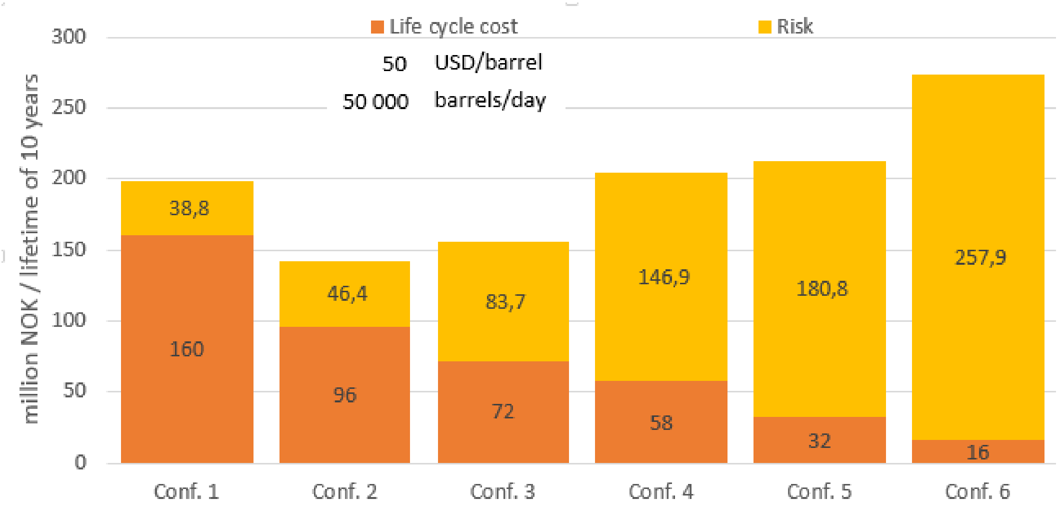

Figure 10: *Total life cycle cost and risk associated with each metering station configuration, in million NOK over a lifetime of 10 years. Example case with a production of 50 000 barrels/day.*

9 CONCLUSIONS

In this study, a method for quantifying the risk associated with different metering station configurations has been developed. The focus has been on oil metering stations, but the principles and methods that are used are transferable to other kinds of metering stations, i.e. multiphase or gas metering stations. Furthermore, an example cost-benefit analysis combining the risk and cost of each metering configuration has been carried out.

The risk modelling was based on that the metering stations can be in the following states:

- Normal operation
- Failure of duty meter resulting in the need to measure flow using only master meter or prover device, resulting in increased uncertainty
- Failure of master meter or prover device, resulting in increased uncertainty
- Failure of all meters, resulting in no measurements from the metering station, hence the uncertainty will be defined by any back up measurements, or production shut down.

In order to calculate the risk, the probabilities for each state were estimated and multiplied with the consequences of each state. The consequences were lost revenue due to mis-allocation resulting from measurement uncertainties, as well as potential loss associated with production shut down.

The overall risk for all the metering station configurations were compared for an example case, and as expected, it was found that the conventional configuration had a low overall risk, and that the risk increased as the metering configuration was simplified. It was found that this increase in risk both originates from the lower reliability of the simpler metering configurations, as well as the higher potential loss due to increased metering uncertainties.

The aim of this study was to develop a framework and a method for comparing and displaying different metering station configurations in terms of risk and cost. The optimal metering station configuration will depend on the various input parameters such as life cycle costs, flow rate, years between planned production stops, the failure rate of the meter, oil price and the expected mean time to repair a meter.

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REFERENCES

[1] Terje Aven, *Pålitelighets og risikoanalyse*, Universitetsforlaget, 1994.

[2] Philip Stockton, Smith Rea Energy Limited, UK, *Cost Benefit Analysis in the Design of Allocation Systems,* North Sea Flow Measurement Workshop, 2009.

[3] Philip Chan, GDF Suez E&P Norge AS, *Bruk av usikkerhetsanalyser og nåverdiberegninger i konseptfasen,* NFOGM nytt nr 2, 2014.

[4] NORSOK, "Annex C, System selection criteria (informative)," NORSOK, 2014.

[5] Dag Flølo, Statoil, *Cost benefit analysis for measurement at pipeline entry,* NFOGM Hydrocarbon Management Workshop – Field Allocation 2014, 2014.

[6] Faure Herman, *Advantages of Master Metering Mathod of Proving Custody Transfer Flows,* June / July 2012.