NORSOK annex on Risk-Cost-Benefit analysis for measurement and allocation systems

Dag Hendrik Flølo, Equinor

INTRODUCTION

NORSOK I-106 (2014) [8] contains an annex called 'ANNEX C System selection criteria (informative)' which describes a simple method for Risk-Cost-Benefit analysis for metering systems. However, the described method only covers the case with 'by difference' allocation between two fields. Therefore, it is not suitable for more complex systems.

For more complex systems, a more general method for Risk-Cost-Benefit analysis is needed. It is therefore appropriate to develop and describe a more general method to facilitate understanding and use but also scrutiny and further development. It is also considered that a better description of the method may facilitate application in other regulations and countries where this kind of considerations are currently not recognized.

The NORSOK I-106 standard is currently subject for revision and has been issued for hearing. The version issued for hearing contains a suggested revision of Annex C.

In the spirit of the Global Flow Measurement Workshop, the main purpose of this paper is to present the suggested revision of the NORSOK standard. In addition, this paper suggests some corrections to the version issued for hearing and adds some comments and explanations.

However, it is not yet known how the NORSOK annex will finally look, or even if the suggested annex will be included in NORSOK standard. Anyhow, this paper stands for itself as basis for understanding, scrutiny, and further development of the methods for risk-cost-benefit analysis for measurement and allocation systems.

There are still some discussions about the validity of equation 18 in section 13 'Risk for loss in allocation systems'. However, the author of this paper thinks the reasoning in this paper is valid and will stand for it until an eventual inconsistency is identified. At the same time the author realizes it might be found wrong or that there might be other perspectives and anyhow that the content and the principles described herein can be expressed better, simpler, or clearer.

In this paper, comments and discussions are clearly identified as sub sections of the relevant chapters of the suggested NORSOK annex. Compared to the version issued for hearing, the section: 'Risk for loss in allocation systems', has been totally revised. The order of the sections is also changed.

Figure 1 illustrates the type of systems that are treated in this paper. The quantities measured by the output measurements are allocated between the input measurements. The quantities that are put into the system have a set of owners. Each owner may own a share in multiple input streams. The quantities that are allocated to an input stream are further allocated between the owners of this input stream.

In a system as illustrated in Figure 1, accurate input measurements of a new field may not be technically or economically feasible. Alternative measurement and allocation concepts may exist. Each of these concepts may have different costs and different measurement uncertainties. Therefore, a method is needed to evaluate and compare the alternative concepts to find the most economically rational measurement and allocation concept.

The described method first covers the situation where none of the owners that are subject to loss from a specific measurement error will regain any of its loss by also owning another share in the system. This method covers the evaluation of an output measurement where the economic interests on the output side and the input side of the output measurements are totally different.

In the section, 13 'Risk for loss in allocation systems', this method is further expanded to cover the situation where one or several owners will regain some of its loss in one ownership share through owning shares in other field(s) in the system.

In practice, multiple systems as described in Figure 1 can be coupled into a larger system. While this may complicate evaluations, the principles described in this paper remain the same. It should be possible to use the same principles also for coupled systems.

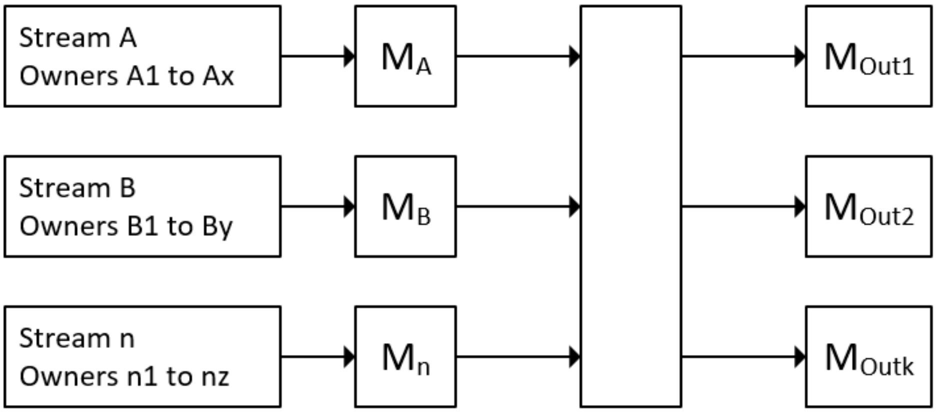

Figure 1 The type of systems treated in this paper. M means measurement. In a 'pro rata' allocation system, all input and output streams are measured. In the case of a 'by difference' allocation system, one of the input streams is allocated the difference: sum of output measurements minus sum of measured input streams.

Please note that a fully developed allocation method may be performed at the level of molecular components and include Pressure Volume Temperature (PVT) simulations of process systems, transfer of mass between liquid and gas phase, impacts on liquid and gas output for the affected fields, or impacts on product values. The described method is not at that level of detail. However, it is believed that the principles of the described method are applicable also at a greater level of detail.

Risk-Cost-Benefit analysis for measurement and allocation systems

Contents

1. Definitions

The following definitions are essential in this annex:

- Allocated quantity: The quantity that is entered into the accounting records of a field and subsequently distributed between the owners (partners) in that field according to the owners share in that field.
- Allocation: [1].
- Allocation by difference: A method for allocation where a field is allocated the difference between a measured output from the production system and the measured input from one or several other fields.
- Allocation measurement: [1].
- Direct measurement: [1].
- Fiscal measurement: A measurement within the scope of the Norwegian Offshore Directorate's '*Regulations relating to fiscal measurement in the petroleum activities'*.
- Indirect measurement:[1].
- Measurement result: [1].
- Error: The difference between the measurement result and the true value
- Pro rata allocation: A method for allocation where each field is allocated a share of the total production that is proportional to its measurement.
- Transaction: A quantity that is recorded as an entry in accounting records and has a monetary effect.

(Definitions marked [1], and other used definitions, can be found in The Norwegian Offshore Directorate's "*Regulations relating to fiscal measurement in the petroleum activities"*.)

2. Objective

Within design and operation of measurement systems, there is often a question if an investment to reduce measurement uncertainty is economically reasonable or if it is reasonable to lax on requirements and accept higher uncertainty.

For allocation measurements, the measurement regulations [1], article 10, states that "the licensee can define other uncertainty limits for measurands than those listed in Table 1, if it can be documented that fulfilling the listed uncertainty limits is not technically feasible or would lead to unreasonably high costs.".

There are also other articles in the regulations where documentation of unreasonably high costs may form a basis for selecting concepts having larger uncertainty than specified by the regulation.

The theory and practices for performing risk-cost-benefit analysis are still developing. However, the aim of this annex is to describe methods to perform risk-cost-benefit evaluation to document 'unreasonably high cost' and help finding the most economically rational metering concept for a project. The same principles can be applied for evaluation of a potential investment to reduce uncertainty, or evaluation of a potential saving that will increase uncertainty.

Note that there are equivalent ways to estimate the risk for loss over the lifetime of a metering system. This annex must therefore be regarded as an explanation of some main concepts rather than a guide that must be followed to do these kinds of evaluations.

3. Risk related to fiscal measurement and allocation of production

An essential characteristic of a fiscal measurement is that the measured quantity is basis for a transaction. A transaction can be transfer of custody to another party, sale, or payment of taxes. A transaction can also be allocation of product to a field or owner in a field.

All measurements have an associated measurement uncertainty. In fiscal measurements, a party in a transaction will have a risk for loss of profit because the measured value can be lower or higher than the true value. All parties in the transaction are exposed to a risk for loss arising from measurement uncertainties or systematic errors.

An allocated quantity is often quantified by an indirect measurement. This means that the input value coming from a flow computer in a physical metering system may be combined with input values from other physical metering systems, analysis results, process simulations, or PVT calculations to calculate the quantity of production that is allocated to a field. The uncertainty of all these inputs, together with the uncertainty of the models and the choice of the allocation principle, will all contribute to the uncertainty of the allocated quantity.

An allocated quantity is still a measurement result that can be accompanied by a statement of uncertainty. Moreover, according to [2]; 3.1.2 it should be accompanied by a statement of uncertainty. In the rest of this annex, the term 'measurement' covers both direct and indirect measurements (e.g. allocated quantity). Consequently, the associated 'uncertainty' and 'risk' cover uncertainties and risks associated with direct or indirect measurements, including allocated quantities.

The risk for loss due to uncertainty in measurement will be reduced if the uncertainty is reduced. However, there is normally a cost associated with reduction of uncertainty. A cost can also be regarded as a risk for loss. A typical purpose of performing a risk-cost-benefit analysis for fiscal measurements in the petroleum industry is to find a technically and economically feasible metering and/or allocation concept that minimizes the total risk for loss related to the concept.

4. Definition of economic risk for loss

This annex is based on the following definition of 'economic risk for loss':

$$ER = P \cdot EV \tag{1}$$

Where:

ER : Economic risk for loss
P : Probability for the potential loss
EV : Economic value of the potential loss

5. Risk for loss due to Uncertainty in measurement

For a normal distribution, a mathematical relationship between the standard uncertainty of a measurement and risk for loss was derived in [4], section 4.1 'Risked exposure to lost revenue', and given in equation (10). The relationship is based on the definition that risk is equal to probability multiplied with consequence. The relationship is there expressed in the form:

$$RLU = \frac{-\sigma}{\sqrt{2\pi}} \tag{2}$$

Where:

RLU = Risk for loss due to Uncertainty in measured quantity (in the unit of the measurand)
σ = One standard deviation of measured quantity (in the unit of the measurand)

It should be noted that even though the measurand in [4] was 'revenue', the mathematical relationship between standard deviation and risk for loss is universal and independent of the unit of the measurand. The universal expression is more versatile and therefore used here. The derivation of the relationship between uncertainty and risk can also be found in ISO/TS 26762:2025; Annex A [5].

As the term 'loss' signifies a negative value, the minus sign can be made implicit. By applying the terminology of [2] the term standard uncertainty u can be used for standard deviation σ. The risk for loss can therefore be expressed as:

$$RLU = \frac{\sigma}{\sqrt{2\pi}} \approx 0{,}4 \cdot u \tag{3}$$

Where:

u = Standard uncertainty for the measurement (In the unit of the measurand)
0,4 = Risk for loss per 1 standard uncertainty[1]

To calculate a risk for loss that has a unit in monetary value, the risk for loss due to uncertainty in measurement will have to be multiplied with the expected economic value of one unit of the measurand:

$$RLU\$ = 0{,}4 \cdot u \cdot V \tag{4}$$

Where:

$RLU\$$ = Economic Risk for Loss due to Uncertainty (in a monetary unit)
$0{,}4$ = Herein named 'Risk factor' = Risk for loss / 1 standard uncertainty
u = Standard uncertainty of the measurement (in the unit of the measurand)
V = Product Value (in monetary unit / unit of the measurand)

Potential gains due to uncertainty in measurement are disregarded. The economic Risk for loss due to Uncertainty ($RLU\$$) is a measure of the risk that value will not be allocated to the rightful owner(s).

[1] A factor of 0,2 has commonly been used but then multiplied with 2 standard uncertainties. This gives identical result to 0,4 multiplied with 1 standard uncertainty

Both the measured quantity, its uncertainty, and the monetary value of one unit of the measurand may vary over time. Considering this variation, the estimation of risk for loss for a metering or allocation concept should be performed for each year over the lifetime of the concept by using forecasted values for that year.

6. Present value of future risks for loss

Consider the situation where metering system cost at present year is intended to prevent future losses. The potential future losses should then be estimated to the value in the defined present year to make the present value of the future losses comparable to the present value of the costs to prevent such losses.

In practice the present value is estimated by multiplying a future economic income (or here: a future risk for loss) with the present value factor:

$$PVfactor = \frac{1}{(1+r)^n} \tag{5}$$

where:
$PVfactor$ = Present Value factor
r = Interest rate for a period, (typically for 1 year)
n = Number of periods

The present value (in year zero) of economic Risk for loss due to Uncertainty in a future year can then be estimated by:

$$PVRLU\$_{(year\ i)} = PVfactor_{(year\ i)} \cdot RLU\$_{(year\ i)} \tag{6}$$

where:
$PVRLU\$_{year\ i}$ = Present Value of the Risk for loss due to Uncertainty, for year i
$PVfactor_{(year\ i)}$ = Present Value factor for the year i
$RLU\$_{(year\ i)}$ = Projected Risk for loss due to Uncertainty, for year i, (in a monetary unit)

It is essential that risks in individual years are expressed in present value before combining risks for individual years into a combined risk over the lifetime of the system.

COMMENTS TO SECTION 6:
The concept of 'present value' may not be intuitive. Also, it may not be intuitive why it is appropriate to use present value calculations in a Risk-Cost-Benefit analysis for evaluation of alternative measurement and allocation systems. The following is therefore an attempt to explain what a present value calculation does and why it is thought of as appropriate to use present value calculations in evaluation of such systems. To simplify the context, all other potential reasons to invest in a project than getting highest possible economic value in return for the investment are here disregarded.

As demonstrated in section 5, there is a relationship between uncertainty in measurement and risk for loss. As will be demonstrated in section 10, costs can also be regarded as risk for loss. In principle, risk for loss from uncertainty and risk for loss from costs are therefore comparable.

However, an investment to reduce risk for loss from uncertainty in measurement will reduce <u>future</u> risks for loss. Therefore, a method is needed to convert the economic value of cost and the economic value of risks at different future times into a comparable unit. That conversion is done by calculating the present value to a defined year, for all future costs and risks.

It is generally expected that companies make investments that are economically sound and provide more value to the companies, and to the society for that matter, than by not making those investments. Investments will have to compete with economic return of putting money in the bank – or rather, buying low risk government bonds. If an investment returns less value than a government bond, it will not be economically sound to do that investment - it would be better to buy bonds.

As there may be higher risk with investments than government bonds, the investments must also provide a better expected return than bonds. Therefore, a company will use a rate of return that is higher than the rate of return on government bonds when making investment decisions. Currently, it seems that a rate of return of around 8 percent per year is in the ballpark of what is commonly used by companies in the relevant industry.

With a rate of return of 8 percent per year, the value of an amount of money will increase year by year. For a specific future value, a present value calculation calculates how much money you would need the present value year (year zero) to have that specific value in a future year.

Figure 2 shows the present value factor as a function of year number. A rate of return of 8 % per year is used to calculate the 'present value factor' according to equation (5). To calculate the present value of a value in year 4, the value in year 4 will have to be multiplied with 0,74 to calculate the present value in year zero.

This means that if a value of 0,74 (in a monetary unit) is invested in year zero, and this investment provides 8 % return on both primary investment and prior returns, the value in year 4 will be 1 (in a monetary unit). In other words, the present value calculation inverts the calculation of the future value of an amount of money invested in year zero, including returns and returns on returns.

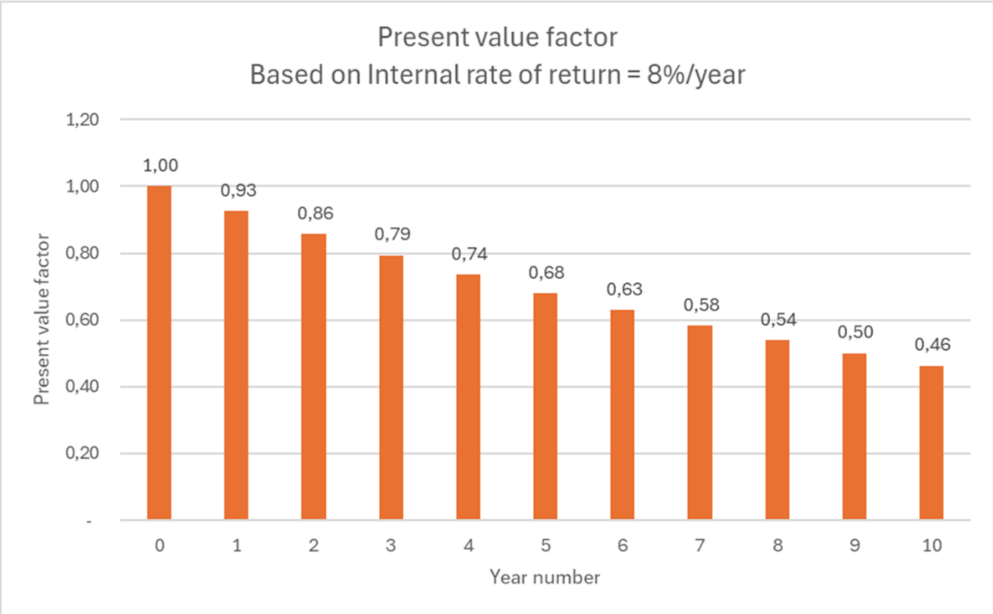

Figure 2 Present value factor shown as a function of number of years. The present value factor is based on 8 % return rate per year.

However, it might still not be intuitive that present value calculation also applies to future risks. Anyhow, it is appropriate to put forward the reasoning why it can be considered to also apply to risks.

Let us say that there is a risk for loss having an economical value of 1 (in a monetary unit) in year 4 and that an amount of money will have to be set aside in year 0 to be able to handle that risk in year 4. A relevant question might then be: How much money will have to be set aside in year zero to pay for that risk in year 4?

The answer to that question is that the money to handle that risk would not be 'set aside' in year 0 – it would be invested. In year 4 the invested amount of money would have grown by yearly returns, including return on returns. If a monetary value of 0,74 is invested in year zero, that amount of money will grow to a monetary value of 1 in year 4 and be sufficient to pay for that risk in year 4. This illustrates why present value calculations also applies to risks. Therefore, it is here considered appropriate to calculate the present value of future risks, $PVRLU\$_{(year\ i)}$, according to equation 6.

While it is not explicitly stated in section 10, it will also be appropriate to calculate the present value of future costs. The reason why present value calculation of costs are not included in section 10 can be found in the following premise in section 6 : "Consider the situation where metering system cost at present year is intended to prevent future losses. The potential future losses should then be estimated to the value in the defined present year to make the present value of the future losses comparable to the present value of the costs to prevent such losses." If the premise that costs incur in the present year (year zero) is not reasonable for a particular evaluation, the present value of costs should also be calculated by the same principle as in equation 6.

As an additional note, alternative measurement and allocation concepts may have investments and risks in different years. To make comparable units, it will therefore be appropriate to calculate present values to the same present value year and use the same rate of return for all costs and risks. This also applies when the value of a measurement and allocation project are compared with the value of alternative investment in other types of projects. As a second note, it can also be seen from the present value calculations that delaying a cost will have a positive value.

In summary, the present value of both future costs and future risks should be calculated before performing a risk-cost-benefit comparison between alternative concepts. When comparing alternative concepts, future costs and risks should be calculated to the same year by using the same rate of return.

7. Interest rate for the present value calculation

It is not obvious which interest rate should be used in the present value calculation. One option is to use a risk-free interest rate - like the rate on government bonds.

However, the party investing in a metering system will have an expectation of future return on their investments that exceeds the risk-free interest rate. This means that competing potential investments may be compared on basis of the expected return on those investments. Rather than investing in a metering system to reduce risk for loss, it may give a higher return to make another investment. This is an argument for using a higher rate of return than the risk-free rate of return. Anyhow, the selected rate of return should be consistent with the rate of return that is conventionally used in the industry and be acceptable to the stakeholders.

COMMENTS TO SECTION 7:

See 'comments to section 6'.

8. Propagation of risk for loss through a measurement model

For a measurement model with uncorrelated input quantities, the 'law of propagation of uncertainty' is given in [2]; section 5.1.2 as (See [2] for nomenclature):

$$u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i) \tag{7}$$

The combined standard uncertainty $u_c\ (y)$is the positive square root of the combined variance $u_c^2(y)$:

$$u_c\ (y) = \sqrt{\sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i)} \tag{8}$$

As shown in equation (3), the Risk for Loss due to Uncertainty is approximately a factor 0,4 times the combined standard uncertainty.

$$RLU \approx 0{,}4\, u_c\ (y) = 0{,}4\sqrt{\sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i)} = \sqrt{\sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right)^2 (0{,}4\, u)^2(x_i)} \tag{9}$$

The equivalence in equation (16) shows that propagation of risk through a measurement model with uncorrelated input quantities follows the law of propagation of uncertainty. This means that calculating the Risk for Loss due to Uncertainty (RLU) by multiplying the combined standard uncertainty of the output with 0,4 is equivalent to multiplying the standard uncertainty of all input quantities with 0,4 before applying 'the law of propagation of uncertainty'.

Likewise, for a measurement model with correlated input quantities, the 'law of propagation of uncertainty is given in [2]; section 5.2.2 equation (16) as:

$$u_c^2(y) = \sum_{i=1}^{N} {c_i}^2\, u^2(x_i) + 2\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} u(x_i) u(x_j)\, r(x_i, x_j) \tag{10}$$

Again, the combined standard uncertainty $u_c\ (y)$is the positive square root of the combined variance $u_c^2(y)$:

$$u_c\ (y) = \sqrt{\sum_{i=1}^{N} {c_i}^2\, u^2(x_i) + 2\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} u(x_i) u(x_j)\, r(x_i, x_j)} \tag{11}$$

And as shown in equation (3), the Risk for Loss due to Uncertainty is approximately a factor 0,4 times the combined standard uncertainty:

$$RLU \approx 0{,}4\, u_c\,(y) = \; 0{,}4\sqrt{\sum_{i=1}^{N} c_i{}^2\, u^2(x_i) + 2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} u(x_i)u(x_j)\, r(x_i, x_j)} \tag{12}$$

Which is equivalent to:

$$RLU = \; \sqrt{\sum_{i=1}^{N} c_i{}^2\, (0{,}4\, u)^2(x_i) + 2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} 0{,}4\, u(x_i) 0{,}4\, u(x_j)\, r(x_i, x_j)} \tag{13}$$

This means that also for correlated input uncertainties, multiplying the combined standard uncertainty with 0,4 is equivalent to multiplying the standard uncertainty of all input quantities with 0,4 before applying 'the law of propagation of uncertainty' to calculate Risk for Loss due to Uncertainty (RLU).

In summary, it can be stated that Risk for Loss due to Uncertainty in measurement propagates through a measurement model by 'the law of propagation of uncertainty. The risk factor 0,4 can either be applied on all input uncertainties or on the output uncertainties.

9. Combined risk for loss over the lifetime of the concept

In a next step, the risk for loss for individual years will have to be combined to a risk for loss over the lifetime of the metering concept.

When calculating accumulated risk from uncertainty over the lifetime of the concept, correlations between the risks for all years must be considered. Calibration intervals, for example, may have an impact on Lifetime Risk for loss due to Uncertainty. If a meter is calibrated once and used all years, the uncertainty may be correlated between all years. If the meter is calibrated every year, the uncertainty may be uncorrelated between all years. The combined uncertainty, and therefore the combined risk, over the lifetime of the project will be different for these two cases and the difference may be significant.

For the extreme case where risk is correlated between all years, the total present value of the lifetime risk for loss will then be (According to [2]; section 5.2.2; NOTE 1):

$$PVLRLU\$ = \sum_{year\ i=1}^{n} (PVRLU\$_{(year\ i)}) \tag{14}$$

Where:
$PVLRLU\$$ = Present Value of the Lifetime Risk for loss due to Uncertainty (in a monetary unit)

For the other extreme case, where risk is uncorrelated between all years, the combined present value of lifetime risk for loss due to measurement uncertainty will be (According to [2]; section 5.1.3; equation (11a)):

$$PVLRLU\$ = \sqrt{\sum_{year\ i=1}^{n} \left(PVRLU\$_{(year\ i)}\right)^2} \tag{15}$$

The proper combination of risks should be decided by considering calibration routines and any other relevant characteristics of the metering concept. In this way, the temporal correlation between measurement uncertainties can be estimated, and in turn the temporal correlation between the risks for all years can be estimated.

10. Risk for loss from lifecycle costs of a metering system

As economic profit from a field is equal to income minus costs, expected lifecycle costs can also be regarded as an 'risk for loss' (of economic profit). By applying the definition of economic risk in equation (1), and considering that actual costs will have probability 1, the 'risk for loss from estimated lifecycle costs' is here considered to be:

$$RLC\$ = P \cdot C = 1 \cdot C = C \tag{16}$$

Where:
$RLC\$$ = estimated present value Risk for loss from the Lifecycle Cost of the metering concept (in a monetary unit)
P = probability for the estimated lifecycle cost (= 1)
C = estimated present value of the lifecycle cost for the metering concept (in a monetary unit)

Note that the uncertainty of cost estimation is here regarded insignificant and therefore disregarded.

11.Total risk for loss of a metering system

As shown above, both lifetime risk for loss due to uncertainty in a measurement ($LRLU\$$) and risk for loss from the lifecycle costs of the metering concept ($RLC\$$) are calculated according to the definition of economic risk in equation (1) and expressed in the same monetary unit. When calculated to the same present value year (year zero), these two risks can be compared or added. For example, they can be added to a total risk for loss related to uncertainty of a measurement and allocation concept.

$$TRUMC\$ = PVLRLU\$ + RLC\$ \tag{17}$$

Where:

$TRUMC\$$	= the Total Risk for loss related to Uncertainty of a Metering Concept (in a monetary unit)
$PVLRLU\$$	= Present Value of the Lifetime Risk for loss due to Uncertainty (in a monetary unit)
$RLC\$$	= Estimated present value Risk for loss from the Lifecycle Cost of the metering concept (in a monetary unit)

The total risk for loss related to uncertainty of the metering concept ($TRMC\$$) can be estimated for each of the technical feasible concepts that are being considered for a project and then be compared.

Rather than calculating the Risk for Loss due to Uncertainty in measurement for two alternative metering concepts, the difference in Risk for Loss due to Uncertainty in measurement can be calculated directly for the difference in uncertainty between these two concepts. The difference in Risk for Loss due to Uncertainty in measurement should then be compared with the difference in lifecycle costs of the two metering systems to evaluate if an investment to reduce measurement uncertainty is reasonable or not.

The method described so far is here considered reasonable for a situation with totally different ownerships. This means that none of the owners subject to loss from a measurement error will regain any of its loss through owning another ownership share in the system. Section 13 and 14 cover the situation where one or several owners, that are subject to loss from a measurement error, will regain some of its loss through owning another share in the system.

12.Selection of the economically preferable metering system

Whenever a metering concept that fully complies with the measurement regulations is at all feasible for consideration, the total risk for loss related to uncertainty ($TRUMC\$$) should be estimated for that concept.

The metering concept that has the lowest total risk for loss related to uncertainty, $TRUMC\$$, may be the preferable metering system if all premises for that method of estimation are reasonable for the context and acceptable to the stakeholders.

However, there may be other risks that can be quantified. For example, risk for shut down which results in lost or deferred production. Other eventual risks might also be estimated by using the definition of risk in equation (1) and be given in a monetary value. Hence, the total risk for loss associated with a metering concept can be further expanded by adding all quantifiable economic risks. Be aware that some risks may only affect one of the fields and should therefore be treated accordingly.

Different metering concepts may have different robustness against failure, feasibility for detection of errors, and feasibility for rectification of errors, possible back–up solutions, tolerance for future changes, and so forth. If these things cannot be quantified, a complete risk-cost-benefit analysis should also contain a qualitative part where these aspects are considered.

Reference [6] and [7] contain relevant information about the principles for risk-cost-benefit analysis, and description of more elaborate methods. In particular, [6] describes a method for evaluation of different metering station layouts where costs, risks related to uncertainty, risks for failure, and potential production shutdowns are all taken into the evaluation. And [7] "device a framework for allocation system modelling that allows for an algorithmic solution to the problem of optimizing the allocation system setup, i.e., choosing the right meter with the right uncertainty at the right place. This includes balancing the risk associated with misallocation due to measurement uncertainty against the cost of realizing the system."

Keep in mind that estimation of uncertainty may itself have significant uncertainty. However, the result may be useful for choosing the optimal metering concept.

It should be emphasized that one premise for the method is that measurement uncertainty is normal distributed. Further, a premise for the uncertainty estimate is that "the result of a measurement has been corrected for all recognized significant systematic effects and that every effort has been made to identify such effects." [2]; 3.2.4.

Further, systematic errors may happen in a measurement concept and the potential for systematic errors may be different between alternative concepts. To quantify the impact of a measurement error, and illustrate the importance of reliable measurement, it may be a good practice to also quantify the loss associated with a reasonable systematic error over the lifetime of the concept.

It should be noted however, that even if a metering project that reduces uncertainty in measurement is both technically feasible and economically reasonable, the metering project may still have to compete with other projects for limited resources. For example, there might be limited capacity to modify a facility, and other potential projects may provide a much better net present value. (Where 'net' means that both costs, risks and income of these projects have been taken into account).

Other characteristics of the metering project will also be evaluated in a project. For example, Health, Safety and Environmental risks. Here, it may be that a metering project reduces the safety of a facility, for example by adding potential leakage points, or adds health risks related to construction or maintenance. There will also be other evaluation criteria that can have an impact the on the decision about which metering and allocation concept is the best in total.

13.Risk for loss in allocation systems

There are many reasonable simplifications and mathematically and statistically equivalent ways of estimating the risk for loss due to uncertainty in a measurement and allocation systems. The purpose of this section is to describe one way to perform such estimation. The method described herein does not exclude any other reasonable way to perform such estimation.

Context

Consider a production or transportation system where productions from multiple fields or streams are commingled. The products exported from this system may then have to be allocated between the fields providing inputs to this system.

The products allocated to a field may further be allocated between the owners in this field. In the upstream petroleum industry, owners often own shares in more than one of the fields. Each owner might then be more interested in its combined economic risk than the uncertainty in measurement of the input from one individual field.

When selecting a measurement and allocation system, it may also be of common and general interest to the affected owners to avoid <u>costs</u> for reduction of uncertainty that exceed the <u>benefit</u> in terms of reduced <u>risk</u> for loss due to uncertainty in measurement.

In this context, one purpose of a 'risk-cost-benefit analysis' is to provide reasonable estimation of risks that can help the project developer to evaluate alternatives and suggest the most economically reasonable measurement and allocation system.

In the following, it is assumed that uncertainty of all input measurements has a normal distribution. The term 'standard uncertainty' is considered equivalent to the term 'standard deviation' (std. dev). The term 'value' means present economic value of the input and output products.

Method for estimating the risk for each individual owner

To estimate the risk for loss from uncertainty in measurement for each individual owner, it is necessary to model the system all the way through the measurement and allocation system to the value allocated to each individual owner. The model for propagation of uncertainties must then be set up in such a way that it calculates risk for loss due to uncertainty for each owner. Following the terminology in section 9, the 'Present Value of the Lifetime Risk for Loss due to Uncertainty' (in a monetary unit) $PVLRLU\$_{owner}$ must be calculated for each individual owner.

For a simple system $PVLRLU\$_{owner}$ may be estimated by analytical or numerical methods according to [2]. For a complex system, this characteristic may have to be performed by a Monte Carlo analysis according to [3]. The Monte Carlo method is summarized in [3] section 5.1.1.

The allocation model is needed to estimate $PVLRLU\$_{owner}$. However, the model does not have to include all details of a fully developed allocation system. The principle stated in [2] is here regarded useful: "Thus implicit in this Guide is the assumption that a measurement can be modelled mathematically to the degree imposed by the required accuracy of the measurement". The model should therefore be suitable to estimate the effects of the significant differences between the systems that are being evaluated. For example, the model should include the allocation mechanism like 'Allocation by difference' or 'Pro Rata allocation'.

The following describes a method where standard uncertainties are propagated through the model by Monte Carlo simulations. In other words, the Mote Carlo simulations are performed in uncertainty domain. Alternatively, Monte Carlo simulations can be performed in risk domain. In risk domain, Risk for loss due to uncertainty ($RLU\$$) can be used in place of standard deviation (std. dev) as input to the Monte Carlo trials.

In Excel, the function 'NORM.INV(RAND(); mean ; std_dev)' can be used to vary each of the input values over its uncertainty distribution. See [3] for guidance on the number of trials. For each individual year, the uncertainty of the value allocated to each individual field and owner can then be estimated by calculating the standard deviation over a set of trials. The standard uncertainty of the trials can then be calculated by the function 'STDEV.P' in Excel.

When combining uncertainties of individual years into combined uncertainty for each owner over the lifetime of the system, it will have to be considered if the uncertainties are mainly correlated or mainly uncorrelated between the years, as explained in section 9. The combination of uncertainties of individual years into uncertainty over the lifetime of the system by the laws of propagation of uncertainty in [2], section 5.2, will here be equivalent to doing that combination by Monte Carlo simulations.

By performing a simulation as described above, the uncertainty of the value allocated to each individual field and each individual owner over the lifetime of the system can be estimated. If simulations are performed in uncertainty domain, these standard uncertainties must then be converted to 'Present Value of the Lifetime Risk for loss due to Uncertainty' ($PVLRLU\$$) by multiplying with 0,4 according to section 5.

Combining risks for individual owners to a single characteristic of the system

According to section 11, a single figure for 'Present Value of the Lifetime Risk for loss due to Uncertainty' ($PVLRLU\$$) is required to estimate the 'Total Risk for loss related to Uncertainty of a Metering Concept' ($TRUMC\$$) (See equation 17).

For the type of systems considered here, there will be three set of owners:

A. The set of owners that will lose value due to a set of measurement errors.
B. The set of owners that will gain value due to that set of measurement errors.
C. The set of owners that are not affected by a set of measurement errors.

An allocation system has the characteristic that the export is allocated between all owners in the system. The value that, due to measurement errors of an input stream, is lost for one set of owners (set A) is gained by the other set of owners affected by uncertainty (set B). Hence, there will be negative correlations between risk for loss for owners in set A and B. Therefore, it would violate the Guide to Expression of Uncertainty in Measurement [2], to add the <u>absolute</u> value of the risks for <u>all</u> owners affected by uncertainty into a combined risk for loss.

It is further considered that set A and B will have equal and negatively correlated risk for loss. This leads to the following definition of a single measurand for which uncertainty and risk can be calculated:

'The projected sum of present values allocated to a set of owners that have positively correlated risk for loss due to uncertainty of measurement and allocation of a new input stream'.

A shorter name for this characteristic may be: 'The combined risk for loss caused by the measurement and allocation system'. The even simpler term: 'combined risk for loss' is used in the rest of this chapter.

In the kind of allocation systems treated herein, it is therefore considered appropriate to add the risks for the owners that have positively correlated risk for loss. This sum will be equal to 50 percent of the sum of the absolute values of the risks for loss for all owners affected by uncertainty of the input measurement subject for consideration.

Therefore, the 'combined risk for loss' can be calculated as the: 'sum of absolute values of the risks for all affected owners' * 50 %. To realign terminology with previous sections, the name 'combined risk for loss' is equivalent to $PVLRLU\$_{System}$ and can therefore be calculated by the following expression:

$$PVLRLU\$_{System} = \frac{1}{2} * \sum_{owner\ i=1}^{n} ABS(PVLRLU\$_{(owner\ i)}) \qquad (18)$$

Where:

$PVLRLU\$_{System}$ = Present Value of the Lifetime Risk for loss due to Uncertainty of the measurement and allocation system (in a monetary unit)

$PVLRLU\$_{(owner\ i)}$ = Present Value of the Lifetime Risk for loss due to Uncertainty for $owner\ i$ (in a monetary unit)

n = Number of owners affected by uncertainty of the considered measurement and allocation system

ABS = Absolute value of…

The 'Total Risk for loss related to Uncertainty of Metering Concept (in a monetary unit)' ($TRUMC\$$) can then be calculated for each of the alternative systems under consideration according to equation (17). Alternative systems can then be compared according to section 11 and 12 to find the most economically reasonable measurement and allocation system for a new input stream.

Use of risk for loss for economic compensation

While the method described above may be thought of as useful to find an economically reasonable measurement and allocation system, it may not be useful for other purposes like economic compensation for risk. For each individual owner, or set of owners, it should be considered that the 'Risk factor' of $0{,}4$ in equation (3) is derived by disregarding the positive side of the normal distribution. This means that for normal distributed uncertainty the probability for loss is equal to the probability for gain, at least where the standard uncertainty of the input measurement is reasonably low. Therefore, the net risk for each individual owner will be zero.

Limitations

The method described above has the limitation though, that the set of owners paying for a metering system may be different from the set of all owners exposed to risk. Further, the value each owner pays for the metering system may not be proportional to the value of the risk each owner is exposed to.

Therefore, this method may not make sense in the perspective of an individual owner. However, the method might be thought of as appropriate by convention between the affected owners. Therefore, the method rests on the following premise, as initially stated in this section 13:

"When selecting a measurement and allocation system, it may also be of common and general interest to the affected owners to avoid costs for reduction of uncertainty that exceed the benefit in terms of reduced risk for loss due to uncertainty in measurement."

COMMENTS TO SECTION 13:

The author has found that for a simple system that is covered by both methods, the method described in section 13 provides the same result as the method in NORSOK I-106 (2014) Annex C [8]. While this can be considered as a good sign, it provides no proof of the method described in section 13 and equation (18).

Unfortunately, the logic behind the following expression in NORSOK I-106 (2014) Annex C [8] is not explained:

$$Average\ difference\ in\ ownership = \frac{1}{2} * \sum_{partner=1}^{n} ABS[(Share\ in\ license\ 1 - share\ in\ license\ 2)] \qquad (19)$$

While it appears intuitively right to some, others struggle to see the logic and what that expression does. The best explanation this author can see is the following. In equation (19), it makes sense to sum the absolute value of the difference in ownership, simply because the sum would be zero if the real values are summed. Thereafter, it also makes sense to divide by 2. Simply because if not divided by 2 the result of the calculation would be a 200 % difference in ownership, rather than 100 %, when the ownership is totally different in the two fields.

Anyhow, the author hopes this paper provides clarity about the method that is propounded herein.

Comment on equation (18)

In section 13 it is stated: "In the kind of allocation systems treated herein, it is therefore considered appropriate to add the risks for the owners that have positively correlated risk for loss. This sum will be equal to 50 percent of the sum of risk for loss for all owners in the measurement and allocation system subject for consideration.". This claim deserves to be explained and demonstrated.

As shown in section 5, 'Risk for loss due to uncertainty in measurement' (RLU) is a characteristic that is proportional to the standard uncertainty of a measurement. Section 8 shows that risk propagates through a measurement model by the 'laws of propagation of uncertainty'. Therefore, the 'Guide to the expression of uncertainty in measurement' [2] is here considered to be the proper standard also for propagation of risk through a measurement model.

However, [2] 1.2 states that: "This Guide is primarily concerned with the expression of uncertainty in the measurement of a well-defined physical quantity — the measurand — that can be characterized by an essentially unique value." It is therefore essential to define a relevant measurand for which uncertainty and then 'Risk for Loss due to Uncertainty' can be calculated.

One might be tempted to define that measurand as: 'The total value that is allocated to all owners affected by the uncertainty of the measurement system under consideration'. However, the uncertainty of that amount would be zero. All the quantity that is available for allocation will be allocated, neither less nor more. Therefore, the risk for loss related to that measurand would also be zero. Therefore, that definition of the measurand would clearly not provide a useful value in a risk–cost–benefit analysis. Hence, another definition of the measurand is necessary.

Before trying to define a useful measurand, it will be helpful to investigate an example illustrating relevant effects. Figure 3 shows an extract of a spread sheet that uses Monte Carlo simulations to simulate 700 trials of an allocation system. The system has 'pro rata allocation' of measured export between two input fields, Field A and B, that both are measured. The productions from Field A and Field B have the same economic value. The metering concept for Field B is under consideration. There are 4 owners in the system. These owners have different ownership in the two fields. Owner # 1 and 2 owns more value in Field A than in field B. Owner # 3 and 4 owns more value in field B than in Field A. This part of the spread sheet summarizes simulations for one individual year for a given standard uncertainty for measurement of Field B.

	A	B	C	D	E	F	G	H
376				**1 std. Dev.* 0,4**	**1 std. Dev.**	**Simulation 1**	**Simulation 2**	**Simulation 700**
377	Total value allocated to owner	Owner # 1	US$	1 754 744	4 386 861	7 720 282 246	7 715 649 249	7 720 431 440
378	Total value allocated to owner	Owner # 2	US$	1 754 744	4 386 861	5 148 265 785	5 143 632 788	5 148 414 979
379	Total value allocated to owner	Owner # 3	US$	1 052 847	2 632 116	1 883 605 686	1 886 385 485	1 883 516 170
380	Total value allocated to owner	Owner # 4	US$	2 456 642	6 141 605	2 394 622 688	2 401 108 884	2 394 413 817
381	Sum of all owners risk for loss (Based on 1 std. Dev.* 0,4)			**7 018 977**				
400	Sum of risks for loss (owner # 1 and 2)		US$	3 509 489				
401	Sum of risks for loss (owner # 3 and 4)		US$	3 509 489				
402	**Sum of all owners risk for loss * 50 %**		US$	**3 509 489**				
403				**Risk for loss ABS*(Prob * average loss)**	**Average**	**Simulation 1**	**Simulation 2**	**Simulation 700**
404	Loss per owner	Owner # 1	US$	1 710 879		-	- 400 133	-
405	Loss per owner	Owner # 2	US$	1 710 879		-	- 400 133	-
406	Loss per owner	Owner # 3	US$	1 063 130		- 2 539 718	-	- 2 629 234
407	Loss per owner	Owner # 4	US$	2 480 636		- 5 926 009	-	- 6 134 880
414	Sum of risk for loss for all owners (Sum of values above)			**6 965 524**				
415	Sum of losses for the loosing owners per simulation		US$			- 8 465 727	- 800 267	- 8 764 114
416	Average loss for the loosing set of owners				- 6 965 524			
417	Sum of risks for loss (owner # 1 and 2)		US$	3 421 759				
418	Sum of risks for loss (owner # 3 and 4)		US$	3 543 766				
419	**Sum of all risk for loss for all owners * 50 %**		US$	**3 482 762**				

Figure 3 The figure shows an extract of a spread sheet that uses Monte Carlo simulations to simulate 700 trials of an allocation system for one individual year. The essential observations are explained in the text.

Figure 3, Row 377 to 380; column D; show the calculated risk for loss (= 1 std. dev.*0,4) for each individual owner. One might be tempted to add the risk for loss for all owners into a combined risk for loss (as shown in row 381). However, that calculation would ignore negative correlations between risk for loss between one set of owners (set A) and the other set of owners (set B). Therefore, adding the absolute value of the risk for all affected owners would violate the laws of propagation of correlated uncertainties, as given by the Guide to the expression of Uncertainty in Measurement [2] (This law is shown in section 8).

The negative correlations can be seen in the lower half of Figure 3. In the rows 404 to 407 'loss per owner'; columns F, G and H; the eventual gains are set to zero. The simulations show that there is one set of owners, owner # 1 and 2, that have positively correlated risk for loss. The simulations also show that the owners in the other set of owners, owner # 3 and 4, also have a positively correlated risk for loss. However, the risks for loss for owners # 3 and 4 are negatively correlated to the risks for loss for owners # 1 and 2.

By positive correlated risk for loss is here meant that if one of the two owners in a set lose some of its rightfully owned value because of a set of measurement errors - then the other owner in the same set will also lose some of its rightfully owned value. By negatively correlated is here meant that if one set of owners lose value – then the other set will gain that value.

Moreover, rows 400 and 401 show that the absolute value of the sum of risk for loss for owner #1 and #2 is equal to the absolute value of sum of risks for loss owner # 3 and 4.

It is therefore considered that there are three set of owners in a such system:

A. The set of owners that will lose value due to a set of measurement errors.
B. The set of owners that will gain value due to that set of measurement errors.
C. The set of owners that are not affected by a set of measurement errors.

It is further considered that set A and B will have equal and negatively correlated risks for loss. The following definition a the single measurand for which uncertainty and therefore risk can be calculated is therefore propounded:

'The projected sum of present values allocated to a set of owners that have positively correlated risk for loss due to uncertainty of measurement and allocation of a new input stream'.

The uncertainties for the owners in this set are positively correlated with correlation factor 1. Therefore, these uncertainties can be added to a total uncertainty. Further, the total uncertainty can be transformed to risk for loss due to uncertainty $RLU\$$ according to equation (4).

It is here considered that the value of that risk is appropriate for calculating the $PVLRLU\$_{System}$ as required for calculation of 'Total Risk for loss related to Uncertainty of Metering Concept (in a monetary unit)' ($TRUMC\$$) as defined in section 11 equation (17).

Eventual generalization of equation number (18)
(The impact of one input stream on total risks in the system)

The method described above estimates the risk from uncertainty in one input measurement. However, the risk for each individual owner will be affected by all input measurements in the system. To estimate the effect of adding a new input stream on the total risk for loss, it may be relevant to estimate how this addition affects the risks for loss when all input streams are taken into consideration.

It is not crystal clear to the author that the following is logically valid. However, it is here propounded that an estimation of the characteristic effect of a new input stream on risk for all affected owners might be done by the following method: Varying all input measurements in each trial of the Monte Carlo simulation using the estimated uncertainty of each of the existing input measurement; Calculating $PVLRLU\$_{Existing\ system}$ according to equation (18); Perform another set of simulations where the new input stream, its uncertainty, and its allocation method is added to the simulation; and calculate $PVLRLU\$_{System\ including\ new\ input\ stream}$ for the system according to equation (18).

The difference between $PVLRLU\$_{Existing\ system}$ and $PVLRLU\$_{System\ including\ new\ input\ stream}$ might then be a measure of the additional risk for loss by adding a new input stream to the system. The difference between alternative measurement and allocation concepts for the new stream can then be calculated by performing this exercise for each of the alternatives and calculate the difference.

As all owners are already exposed to risk for loss from uncertainty in measurement in the existing system, and the uncertainty of the new system may be uncorrelated with the uncertainty from the existing measurements, the additional risk for loss from adding a new stream will be lower than if the risks in the existing system are disregarded in the evaluation.

Inclusion of export measurements in the estimation
While it may be tempting to include the uncertainty of the output measurement in the same calculation as described in previous sub section, it must be considered if equation (18) still holds for this combination. This may not be the case. It may therefore be that the risk for loss from uncertainty of output measurements

may have to be treated separately or combined with risk for loss from input measurements by an appropriate method.

14.Simplified estimation of risk for loss in an allocation system

Consider a context where production from a Field B will deliver petroleum into an existing production system for Field A. Further, the considered allocation method is that Field B will be allocated the quantity that is measured by a metering system for field B. Field A will be allocated the difference between the measured total export and the measured input from field B. In other words, production from Field A will be 'measured by difference'. It is also considered that the export is measured with a very low uncertainty.

For screening of potentially feasible metering systems, it may then be useful to have an estimate of the change in Risk for loss due to Uncertainty if the uncertainty of Field B is increased by 1 % (at 2 standard uncertainties).

1. Use a relative standard uncertainty of 0,5 % to calculate uncertainty u in unit of the measurand for use in equation (4)

2. Calculate $RLU\$_{Field\ B}$ by using equation (4)

3. Calculate $PVLRLU\$_{Field\ B}$ by using equations (5), (6) and (14) or (15)

4. As whatever is lost by Field B is gained by Field A, the risk for each individual owner j in the two fields can then be calculated by:

$$PVLRLU\$_j = PVLRLU\$_{Field\ B} * \frac{(SA_j - SB_j)}{100} \tag{20}$$

   Where:
   $PVLRLU\$_j$= combined Risk for Loss, for owner j, from Uncertainty in measured amount over the Lifetime of the metering concept (in a monetary unit)
   SA_j = owner j share in field A (%)
   SB_j = owner j share in field B (%)

5. To calculate the risk that production will be allocated to the wrong owners because of uncertainty in measurement, the following expression can be used:

$$PVLRLU\$_{Owners} = PVLRLU\$_{Field\ B} * \frac{1}{2} * \sum_{owner j=1}^{n} \frac{ABS(SA_j - SB_j)}{100} \tag{21}$$

   Where:
   $PVLRLU\$_{owners}$= Risk for allocation of production to the wrong owners of Field A and B (in a monetary unit)
   n = total number of owners in field A and B
   $owner\ j$ = an owner in field A, Field B, or both

The expression $\frac{1}{2} * \sum_{owner j=1}^{n} \frac{ABS(SA_j - SB_j)}{100}$ quantifies the difference in ownership between field A and field B.

$PVLRLU\$_{Owners}$ can be thought of as the fraction of $PVLRLU\$_{Field\ B}$ that is risked being allocated to the wrong owners in Field A and B after having taken into account that some owners may own a share in both Field A and Field B.

For any difference in uncertainty between two alternative metering systems, the propagated risk can then easily be scaled up or down from $PVLRLU\$_{Owners}$ (which is calculated for a 1% relative uncertainty at 2 standard deviations) by multiplying $PVLRLU\$_{Owners}$ with the difference in relative uncertainty (%) between two alternative metering systems).

Sometimes, the Present Value PV of planned production is already known for a project. A back-of-the-envelope calculation of the risk associated with a 0,5% standard uncertainty (= 1% at two standard uncertainties), which is correlated over the lifetime of a measurement system, can then be performed by the expression:

$$PVLRLU\$_{Owners} = PV * 0{,}5\ \% * 0{,}4 * \frac{1}{2} * \sum_{owner j=1}^{n} \frac{ABS(SA_j - SB_j)}{100} \tag{22}$$

Where:
PV = Estimated Present Value of measured quantities over the planned lifetime of the measurement system.

As before, the result can easily be scaled up or down according to estimated uncertainty of a concept. The result can be used to help identification of alternative metering and allocation concepts that can possibly be economically reasonable.

COMMENT TO SECTION 14:
The method described in this section is consistent with NORSOK I-106 (2014) Annex C [8]. For the context described in section 14, the method is also consistent with the results of the method described in section 13.

15.Tax influence from risks for loss

For payment of tax, one might think that a government pays none of the investment costs and therefore have no other interest than having lowest uncertainty in the measurements that form basis for taxes. However, there is normally a kind of petroleum tax that is proportional to the profit of the field. (in Norway, the petroleum tax is currently (2025) 78% of economic profit).

In its simplest form, the economic profit will be:

$$EP\$ = I\$ - C\$ \tag{23}$$

Where:
$EP\$$ = Economic Profit of a field (in a monetary unit)
$I\$$ = Income from sale of product (in a monetary unit)
$C\$$ = lifecycle Costs of the field (in a monetary unit)

As the cost of the metering concept will increase the lifecycle costs of the field, the economic profit of a field will also be reduced by that cost. The tax income will then be reduced proportionally to the reduction in economic profit of a field and therefore proportionally to the lifecycle cost of the metering concept.

With a high tax rate, the government may therefore share the interest of the operators to find the metering concept with the lowest total risk for loss. This may also be sound in a socio-economic perspective.

It may also be that the state owns a share in a field and therefore share the interest of the other owners in minimizing the total risk for loss related to the metering concept of that field.

Anyhow, the Risk for loss due to uncertainty in measurement should be communicated with stakeholders and authorities to get acceptance for the proposed metering and allocation concept and the associated risks for loss.

16.References

References in the main chapters:
[1] Regulations relating to fiscal measurement in the petroleum activities; 01.05.2023; Including changes; FOR-2023-12-19-2181 from 01.01.2024.

[2] ISO/IEC GUIDE 98-3:2008(E); Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)

[3] ISO/IEC GUIDE 98-3-SP1:2008; Uncertainty of measurement; Part 3: Guide to the expression of uncertainty in measurement (GUM:1995); Supplement 1: Propagation of distributions using a Monte Carlo method

[4] Phillip Stockton; Cost Benefit Analyses in the Design of Allocation Systems; 27th International North Sea Flow Measurement Workshop 20'th – 23'rd October 2009. (The paper is freely available at the web site for NFOGM.)

[5] ISO/TS 26762:2025 'Design and operation of allocation systems used in gas productions facilities'; 21 April 2025

[6] Skålvik, A. M., Bjørk, R.N., Frøysa, K.-E. and Sætre, C. 'A new methodology for cost-benefit-risk analysis of oil metering station lay-outs'; 33rd International North Sea Flow Measurement Workshop; 20. – 23. October 2015.

[7] Pobitzer, A., Skålvik, A.M. and Bjørk, R.N. 'Allocation system setup optimization in a cost-benefit perspective'; Journal of Petroleum Science and Engineering, 2016

References used in introduction, comments, and additional chapters:

[8] NORSOK I-106:2014; Fiscal metering systems for hydrocarbon liquid and gas; Published: 2014-11-18.

[9] NORSOK I-105:1998; Fiscal measurement systems for hydrocarbon liquid; Published: 1998-06-01.

Historical stages in the development of the method

Methods for performing risk-cost-benefit analysis have been developing since the 1980's. Some of the main steps in this development are summarized below.

As the petroleum sector on the Norwegian shelf developed, some smaller petroleum fields were discovered in the vicinity of larger fields. It was found economically reasonable to develop these fields as tie-ins to planned or existing installations on the larger fields. It was clear that these tie-ins would have to be measured and that uncertainty in measurement represented a risk for loss of entitled products for the affected fields and owners.

Historically there has been a misconception that the uncertainty at 2 standard uncertainties was a direct measure of risk. However, it was realized by some that this misconception gave an unreasonably high perception of risk and that it would cause unreasonably large investments in measurement. Some then expressed the loosely founded idea that an investment to reduce uncertainty could be regarded as an insurance premium and that no one would pay the full value of the insured value to avoid a loss of that value. This gave rise to the idea of multiplying 2 standard uncertainties with a factor to find a more suitable value for how much the owners would be interested to invest in reduction of uncertainty. This way of thinking resulted in a range of factors being used, typically ranging from 0,25 to 0,5.

This way of thinking is evident in NORSOK I-105:1998 [9]; Section C.1.2 'For metering systems for satellite fields with tie-in and processing on existing field platforms'. In section C.1.2 it is stated:

"An analysis shall be performed to quantify: a) The monetary value of 1 % reduction in measurement uncertainty for oil and gas based on difference in ownership between satellite field owners and existing field owners, during the lifetime of the installation. (Assuming for example that owners are willing to use 0,25 NOK maximum to reduce measurement uncertainty by 1,0 NOK)".

This shows that the mathematical relationship between 2 standard uncertainties and risk for loss was not yet known, and that a factor of 0,25 was thought of as being sensible, even though there was no firm reasoning behind it.

In 2009, Phillip Stockton presented the paper: 'Cost Benefit Analyses in the Design of Allocation Systems; at the North Sea Flow Measurement Workshop [4]. In section 4.1, Stockton showed how to use the definition of risk (probability * consequence) and integrate this product over the loss side of the normal distribution. Surprisingly, that integral solved very nicely. Stockton found that a factor of ca. 0,2 represented a mathematical relationship between 2 standard uncertainties and risk for loss.

It was a relief to those that had been using risk-cost-benefit analysis at the time that the loosely suggested factor of 0,25 was not far off a mathematically derived factor of 0,2. It was also a relief that a loosely founded and subjective factor could now be replaced with a factor that was mathematically derived.

While being applied from the moment it was known (2009), the factor of 0,2 was taken into the NORSOK I-106 standard in 2014 (Annex C). Compared to earlier versions of the relevant NORSOK standard, the method for cost-benefit analysis now also included a way to handle differences in ownership. Difference ownership was handled by applying the factor called 'average difference in ownership'.

Still, the method in Annex C: Was not explicit on combination of uncertainty over the lifetime of the system; mistakenly used the term 'Net Present Value' where the term 'Present Value' should have been used; was not detailed on calculation of present value; was not able to handle allocation systems with more than two fields; was only suitable for measurement by difference; and it did not mention that the allocation method would have an impact on uncertainty.

In a recent development, the mathematical derivation of the relationship between uncertainty and risk for loss is now also included in the Technical Specification ISO/TS 26762 (2025) [5], Annex A. While the TS states that "Any measurement improvements should be justified by a cost benefit analysis", the specification does not contain further details on how to perform risk-cost-benefit analysis. Basically, the level of details on the method stops at the statement "To carry out a cost benefit analysis, it is necessary to understand the theory of uncertainty as the well as the exposure to loss (see Annex A) and how to determine this in a system".

There has been multiple papers and presentations on themes related to risk-cost-benefit analysis over the years. On NFOGM.no, there is an archive that gives access to many of these. Relevant papers and presentations can be tracked down by first searching for the main authors on the reference list.

It should also be mentioned that there is still a paradox associated with the methods for risk-cost-benefit evaluations. More specifically, the paradox of ignoring the probability for gain (due to uncertainty in measurement) in the risk evaluations. For normal distributed and relatively low uncertainties, the risk for loss will be equal to the risk (opportunity) for gain. Hence, the net risk will be zero. Stockton has addressed this paradox in some of his presentations and papers. As per now, there is no firm solution to this paradox.

Hopefully, this paper covers the shortcomings of Annex C in NORSOK I-106 (2014) and ISO/TS 26762 and documents a method that is suitable for further development.

Acknowledgements
The author appreciates valuable feed-back to early drafts from Ranveig Nygård, and Astrid Marie Skålvik, NORCE. The author also appreciates valuable feedback and discussions with Philip Stockton (Accord), and Kjetil Folgerø, (NORCE).

Reviews, comments, discussions, and support from colleagues Arne Morten Dahl, Vegar Ingdal Hansen, and Øyvind Nesse (All in EQUINOR), to multiple revisions of this paper and the presentation of it have also been very valuable and is greatly appreciated.

While all these persons have provided valuable contributions to the development of this paper, none of them are to be blamed for anything written herein. The author takes full and sole responsibility for the content.