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Analysis of Field and Ownership Allocation Uncertainty in Complex Multi-field Configurations

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ABSTRACT
Current focus on cost-effective developments of new hydrocarbon fields aims at exploiting the capacity of existing production units to the maximum using a number of tie-ins to subsea developments. This results in increasingly complicated process flows, where individual multiphase streams may or may not be measured. This increased complexity makes design and analysis of allocation systems a challenging task.

Allocation principles, metering system setup, use of test separator time, ownership structure, flow rates and life time profiles are all factors which affect the field and ownership allocation uncertainty. In order to find how each field or each owner is exposed to economic risk associated with measurement and allocation uncertainty, an uncertainty analysis combined with a risk-cost-benefit analysis should be carried out. Traditionally, the analysis of such allocation systems is based on analytic calculations. These calculations increase rapidly in complexity as the process flow becomes more complicated. For systems with several tie-ins and satellites, and with a fragmented ownership, powerful numerical methods are required to perform this analysis.

This paper demonstrates the **calculation of field and ownership allocation uncertainty** for realistic measurement setups and allocation scenarios in a multi-field setting based on industrial projects. A flexible framework for analysis of complex multi-field configurations is used in these numerical calculations, which are based on an ISO GUM (ISO/IEC, 2008) compliant Monte Carlo technique.

Further on, **it is demonstrated how different field configurations, ownership structures, allocation principles, meter uncertainties and flow rates affect the total cost and risk for each owner**. This investigation includes the exposure to **economic risk associated with measurement uncertainty** associated with the different alternatives. We also give examples of how the **lifetime cost** of the metering system may vary depending on choices in **allocation principle, flow rate profiles, as well as placement and calibration** scheme of the individual meters. A particular focus of our work is how each owner is exposed to misallocation risk. In this context it is mandatory to take into account the **correlation** between the uncertainties in the field-allocated streams. Failure to include these correlations may result in erroneous

estimations of each owner's economic exposure due to misallocation, and may thus potentially result in sub-optimal field developments.

Through **realistic example systems based on industry projects**, it is shown how an **uncertainty analysis** combined with a **risk** analysis may provide valuable insight into the exposed economic risk for each owner due to misallocation. It is demonstrated how thorough knowledge and understanding of the allocation uncertainty is essential in order to minimize each parties' economic exposure, especially in real-life complex allocation systems.

1   INTRODUCTION

The aim of this paper is to demonstrate the calculation of field and ownership allocation uncertainty for realistic measurement setups and allocation scenarios in a multi-field setting based on industrial projects. Allocation uncertainty entails a financial risk in the form of an exposure to losses due to misallocation as discussed in Section 2.

In order to estimate these allocation uncertainties correctly, thorough knowledge and understanding of the allocation uncertainty is essential. The field allocation uncertainty is influenced by a number of parameters: Metering station uncertainties (or uncertainty related to performance curves in the cases where no metering station is installed), use of test separator time, production profile, fluid composition, uncertainty in process parameters, system topology and the allocation principles agreed upon among other things.

Recognising that the field allocation uncertainty may differ significantly from the individual metering station uncertainties, it is essential to have correct and effective methods for estimating this uncertainty. As there are many influencing parameters as exemplified above, these calculations increase rapidly in complexity and powerful numerical methods are required to perform this analysis. In this paper we present a flexible framework for such an analysis based on an ISO GUM [1] compliant Monte Carlo technique as shown in Section 3.

For many companies dealing with fiscal measurements of hydrocarbons, the overall question is what economic risk their company is exposed to. In order to answer this question, the ownership uncertainty must be estimated and based on this, the risk each owner is exposed to may be evaluated. When estimating the ownership uncertainty, it is mandatory to take into account the correlations between the field allocated quantities. These correlations stem from the chosen allocation setup itself and may significantly influence the ownership uncertainty. This topic is further discussed in Section 4.

In Section 5 we show a number of examples illustrating the financial risk in the form of an exposure to losses due to misallocation as a direct consequence of metering uncertainty, flow rates and allocation principles. We illustrate important concepts in small, constructed systems before analysing a real-life complex allocation system.

Regarding the notation applied throughout this paper, we refer the reader to section 7.

Beyond illustrating exposed economic risk for each owner due to misallocation through realistic example systems based on industry projects, this paper has three main messages:

- The field allocation uncertainty will in many cases differ significantly from the individual metering station uncertainties (dependent on the system setup).
- In most real life setups, it is not intuitive to decide which owner(s) that are most exposed to economic loss due to misallocation.
- It is mandatory to take into account the correlation between the uncertainties in the field-allocated streams in order to estimate the owner allocation uncertainty correctly.

2 ECONOMIC RISK DUE TO ALLOCATION UNCERTAINTY

In estimating the allocation uncertainty of a system, several metering station uncertainties are included. Typically, one of them is an export measurement with low uncertainty, while others may be multiphase measurements with higher uncertainties or stem from performance curves with even higher uncertainties.

If a fiscal measurement result is different from the "true" value, then erroneous numbers are used in the allocation calculations, and the allocated quantities to each well or each field will thus also be erroneous. One possible consequence of this may be that decisions regarding field development are taken based on flawed information, which in the end may result in a less optimal field exploitation.

Another possible consequence, which we discuss in this paper, is the possibility of inaccurate allocation of revenue between the various owners. Thus each owner is exposed to an economic risk associated with measurement and allocation uncertainty, also referred to as potential loss due to misallocation.

The risk of an undesirable event is commonly quantified by the loss associated to the event multiplied by its probability [2]. The key undesirable event in allocation systems is misallocation, or perhaps more precisely under-allocation, due to allocation uncertainty.

In [3], Philip Stockton demonstrates one way of quantifying the economic risk associated with allocation uncertainty. The definition of economic risk in equation (1) is based on [3], given here with slightly modified notation:

$$R = \frac{U \cdot V}{k \cdot \sqrt{2\pi}}$$

(1)

In Equation (1), R represents the exposure to lost revenue of a quantity with an associated uncertainty, illustrated by the yellow part of Figure 1. U is the absolute expanded uncertainty of the quantity, k the coverage factor for the given confidence level, and V is the value per unit of the quantity. For oil volume allocation, U could be the absolute expanded uncertainty of oil volume in barrels, and V the oil price per barrel. Simply explained, this equation comes from assuming that the allocated quantity has a normal distribution, and then integrating this distribution from the mean allocated value to minus infinity. This is illustrated in Figure 1.

Figure 1: Illustration of principle for calculating economic risk associated with allocation uncertainty.

A common misconception is that "you lose some, you win some", i.e. that misallocation related to allocation uncertainty will "even out" after a while. Stockton [3, pp. 3-5] explains thoroughly how the assumption that uncertainty "even out" over time is erroneous in most cases and the examples below are based on the same paper.

Masking of systematic errors/meter bias: One reason why the uncertainty may not "even out" after a while is that a high uncertainty may mask a systematic error. If the uncertainty of a metering station for instance is 10 %, it may be difficult to detect a systematic error of for instance 2 %. If the value of the product flowing through this metering station is for example 100 000 USD/day, this masked, uncorrected systematic error would result in a daily economic loss of 2 000 USD/day.

Allocation bias: Let A and B be two fields producing 100 units each per day. Allocation follows the pro rata principle. Field A's production and the export measurement have a negligible uncertainty and Field B has an uncertainty of 10 %.

The first day 110 units are measured from Field B, and $\frac{110}{100+110} \cdot 200 = 104.8$ units are allocated to Field B. The next day 90 units are measured, and only $\frac{90}{100+90} \cdot 200 = 94.7$ units are allocated to Field B. Even though the sum measured at Field B the two days equals 200, only $104.8 + 94.7 = 199.5$ units are allocated to Field B. This equals a systematic under-allocation of 0.25 %. Note that this under-allocation is systematic, meaning that statistically 0.25 % of Field B's allocation is allocated to Field A instead, and the owner of field B will not be paid for 0.25 % of the fields production.

3   CALCULATION OF FIELD ALLOCATION UNCERTAINTY

As explained in section 2, the potential loss due to misallocation is a direct consequence of allocation uncertainty which in turn is dependent on uncertainties of measurements and/or flow estimation. It is thus essential to estimate the allocation uncertainty in a proper manner. Note that the allocation uncertainty for a field or tie-in is often different from the field metering station uncertainty, as illustrated in Figure 2. The reason for this is that the other uncertainties in the system affect the allocation uncertainty of each field, through the allocation calculations. An exception to this is the case of by-difference allocation, here all

fields with measurements have an allocation uncertainty equal to their measurement uncertainty.
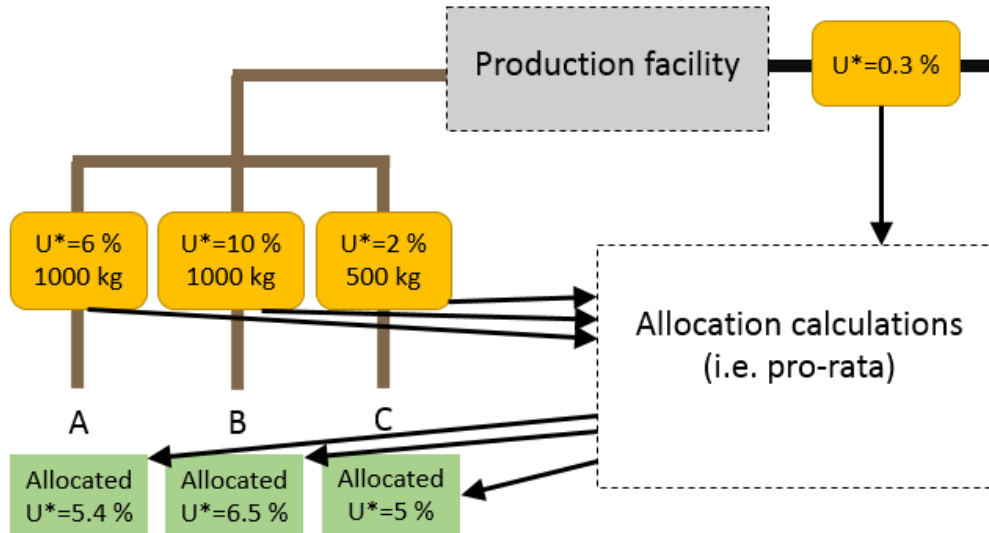
Figure 2: Illustration showing that field allocated uncertainty is in most cases not identical to the field measurement uncertainty. The allocation uncertainty depends on the other uncertainties in the allocation system, the flow rates and the allocation principle. In the figure U* denotes the relative expanded uncertainty of the measured and allocated quantities.

The uncertainty in field allocated quantities can be calculated using analytical or numerical methods. For straightforward allocation systems with few tie-ins and a limited number of gas lifts as well as water or gas injections, it is possible to calculate the allocation uncertainties using an analytic approach. This is done by writing down all allocation calculations, performing partial derivatives of all input parameters and then calculating the combined uncertainty according to the method described in ISO GUM [4].

However, as the process flow becomes more complicated, these calculations increase rapidly in complexity. For systems with several tie-ins and satellites, as well as several gas lifts or water or gas injections, the analytic approach may be time-consuming and difficult to achieve. It is therefore advantageous to apply more powerful numerical methods to calculate the allocation uncertainties. Supplement 1 to ISO GUM [1], describes how the propagation of uncertainties through a system may be calculated using a Monte Carlo method.

In this section, we show how an **ISO GUM-compliant Monte Carlo method** may be used to calculate allocation uncertainties. Easily explained, we model each input parameter by a probability distribution instead of only one value. The standard deviations of these distributions are set based on the uncertainty of each of the parameters. The distributions are then combined and commingled according to the allocation calculations, and the standard deviations of the resulting distributions indicate the uncertainty of the allocated quantities. Figure 3 illustrates this method.
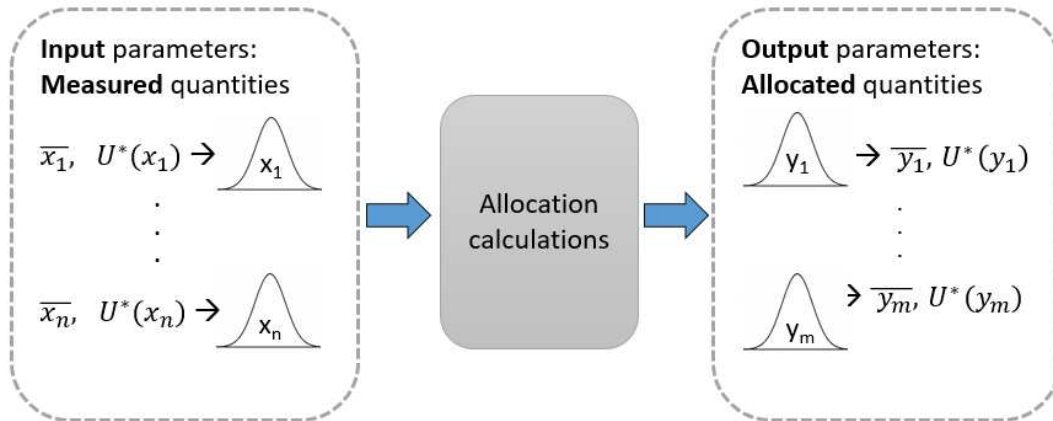
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Figure 3: Illustration of a Monte Carlo based method for calculating allocation uncertainties. Whereas the input distributions are depicted as normal distributions in the figure, this is not a requirement for using the Monte Carlo method. In the figure $U^*(x_i)$ symbolizes the relative expanded uncertainty of a quantity x_i, and $\bar{x}_i$ its average value. Similar symbolism applies to y_i.

The **major advantages** of using a numerical Monte Carlo (MC) approach, as compared to the analytical calculations, are the following:

- More complex allocation systems can be analysed using the MC approach, while the analytical approach is laborious and cumbersome for complex systems.
- The analytical approach is based on the assumption that the input parameters follow normal distributions, which are linearly combined in order to produce the output distributions. Using the MC approach, none of these assumptions are required.
- Any correlations between input parameters are easily taken into account by generating correlated input distributions.

The field allocation uncertainty gives valuable information regarding how each *field* is exposed to economic risk. In our context, each field may consist of several satellites and tie-ins which in turn may have a number of owners. For each of these owners, the most interesting question to highlight is the economic risk to *their* particular company in the overall picture. In order to examine this question, we need to estimate the ownership allocation uncertainty. This is the topic of section 4.

4   OWNERSHIP ALLOCATION UNCERTAINTY

In order to evaluate the risk each owner is exposed to, it is necessary to find the ownership allocation uncertainties. In cases with only one single owner of each field, the ownership allocation uncertainty coincides with the field allocation uncertainty. In reality, a more fragmented ownership structure is often the case, due to more complex field development with several tie-ins and satellites.

4.1 The Intuitive Method is Often Incorrect

When allocating the total exported production between the various owners, the various field production streams are multiplied with the ownership matrix. A common misconception is that the same can be done with the field allocation uncertainties in order to find the ownership allocation uncertainties. However, if one simply multiplies the field allocation uncertainties with the corresponding ownership fractions, and add the resulting uncertainties together for each owner, there is an indirect, often incorrect, assumption that all field allocated uncertainties are correlated with a correlation coefficient of +1. Following the method for combining correlated uncertainties as described in ISO GUM [4], this intuitive but erroneous method can be written as:

$$U_{owner\,1} = F^{owner\,1}_{field\,A} \cdot U_{field\,A} + F^{owner\,1}_{field\,B} \cdot U_{field\,B} \quad \textcolor{red}{\leftarrow assumes\ r_{A,B} = +1} \quad (2)$$

Here $F^{owner\,x}_{field\,y}$ is the ownership fraction for owner x in field y. U^* symbolizes relative expanded uncertainty of the quantity allocated to a field or to an owner and Q_A and Q_B are the measured productions of Field A and B respectively.

Another possible way of estimating the ownership uncertainty which might seem intuitive at first glance is to compute the sum of squares of the allocated quantities:

$$U_{owner\,1} = \sqrt{\left(F^{owner\,1}_{field\,A} \cdot U_{field\,A}\right)^2 + \left(F^{owner\,1}_{field\,B} \cdot U_{field\,B}\right)^2} \quad \textcolor{red}{\leftarrow assumes\ r_{A,B} = 0} \quad (3)$$

However, this approach is based upon the assumption that all field allocated uncertainties are uncorrelated which is often not the case.

4.2 Correlation between Field Allocated Streams due to Allocation Equations

In real-life systems, the correlation coefficients between the various fields are seldom +1 or zero, and can even be negative in many cases. The correlation comes from the allocation principle itself; the sum of the production allocated to each field must equal the exported production. In most cases, the export metering station from the cluster of fields has a lower metering uncertainty than the meters measuring the production from the individual satellite fields to the mother field. This is due to the fact that while the export production is separated and then measured using single phase meters, the different field streams are often measured using multiphase meters, or single phase meters after 1st stage separators with more or less incomplete separation. The production from a field may also just be estimated based on individual well measurements and performance curves, which may result in an even higher uncertainty.

Consider a simplified allocation system with two fields A and B. If too much production is allocated to Field A, then it logically follows that too little is allocated to Field B, as the sum of the two field allocated streams must equal the measured export production. In other words, the allocated production between fields A and B have negative correlation.

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4.3 Correlation between Streams due to Correlation in Input Parameters

The field allocated streams may also be correlated due to correlation in the measurement instrumentation or in the performance curves used to estimate field production. Flow meters used at different points in the measurement system that have been calibrated at the same flow laboratory or with the same prover may have correlated measurement uncertainties.

Another example is that flow meters based on the same measurement technology may have the same deviations due to changes in flow profile, scale build-up etc. For these cases, if one meter is under- or overestimating the flow, then a meter with similar technology or shared calibration facilities, in general may be expected to deviate in the same direction. A similar behaviour may be expected for performance curves based on the same model. The correlation coefficients between different meters and modelling uncertainties are therefore often positive.

Using the proposed numerical Monte Carlo-framework, it is straightforward to generate correlated input distributions.

4.4 Different Methods for Including Correlations in the Ownership Allocation Calculations

The correlations between the various field allocated streams must be taken into consideration in order to obtain a proper estimate of the ownership allocation uncertainty. This can be done using different methods:

- Analytically: Write down the ownership allocation equations so that the production allocated to each owner is expressed directly from the input parameters and measurements together with the ownership matrix.

$$U^*_{owner\,1} \qquad (4)$$

  This method gives valuable insight into what drives the allocation uncertainty for each owner, but the analytical calculations are intricate and time-consuming.

- Calculate the correlation coefficients between the various field allocated streams either analytically or numerically, and then calculate the ownership allocated production using the method described in ISO GUM [4] :

$$(U^*_{owner\,1})^2 = \left(F^{owner\,1}_{field\,A} \cdot U^*_{field\,A}\right)^2 + \left(F^{owner\,1}_{field\,B} \cdot U^*_{field\,B}\right)^2 + 2r_{A,B}.F^{owner\,1}_{field\,A} \quad (5)$$
$$\cdot U^*_{field\,A} \cdot F^{owner\,1}_{field\,B} \cdot U^*_{field\,B}$$

- Multiply the field allocated distributions with the ownership matrix, and find the ownership allocation uncertainties from the resulting distributions as in a Monte Carlo approach:

$$U^*_{owner\ 1} = k \times \text{standard deviation of:}$$
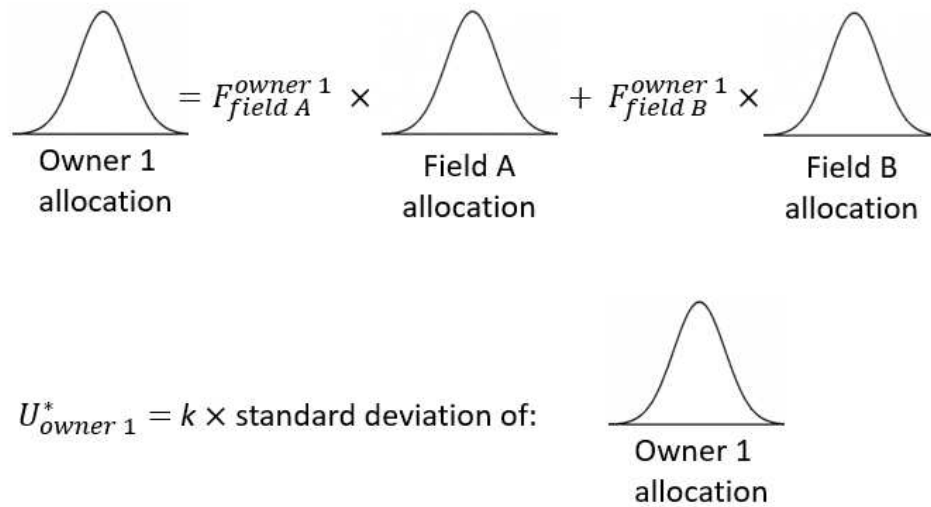
Figure 4: Illustration of how the correlation between field allocated quantities can be taken into account by multiplying the ownership fractions with the allocated field distributions. In the figure, U^* symbolizes relative expanded uncertainty of a quantity, F symbolizes ownership fraction and k is the coverage factor applied to estimate the expanded uncertainty. For the standard normal distribution at 95 % confidence interval this factor equals 1.96.

As described in chapter 3, the field allocated distributions are output from the numerical allocation calculations we use in this paper. In the examples presented in this paper, we have therefore applied the third method where the field allocated distributions are directly multiplied with the ownership fractions. Note however that if the calculations are carried out correctly, all the three different methods above are expected to produce the same results[1].

5 ANALYSIS OF COMPLEX MULTI-FIELD CONFIGURATIONS BASED ON REAL LIFE SYSTEM

In order to illustrate the principal effects related to how different field configurations, ownership structures, allocation principles, meter uncertainties and flow rates affect the total cost and risk for each owner we start out by a small, simplified example. This is done for educational purposes in order to highlight the effect of specific parameters. We then proceed to a larger real-life system illustrating the real usefulness of such an analysis framework in situations where a manual cost-benefit analysis becomes tedious. The numerical Monte Carlo based framework applied for analysis of these multi-field configurations is shown in Figure 5. In this illustration there are three hydrocarbon streams, one multiphase metering station (MPFM), one virtual flow metering station (VFM) in addition to export oil and gas metering stations and a production facility. The figure illustrates the process of performing allocation calculations including allocation uncertainty and the transition to ownership allocation.

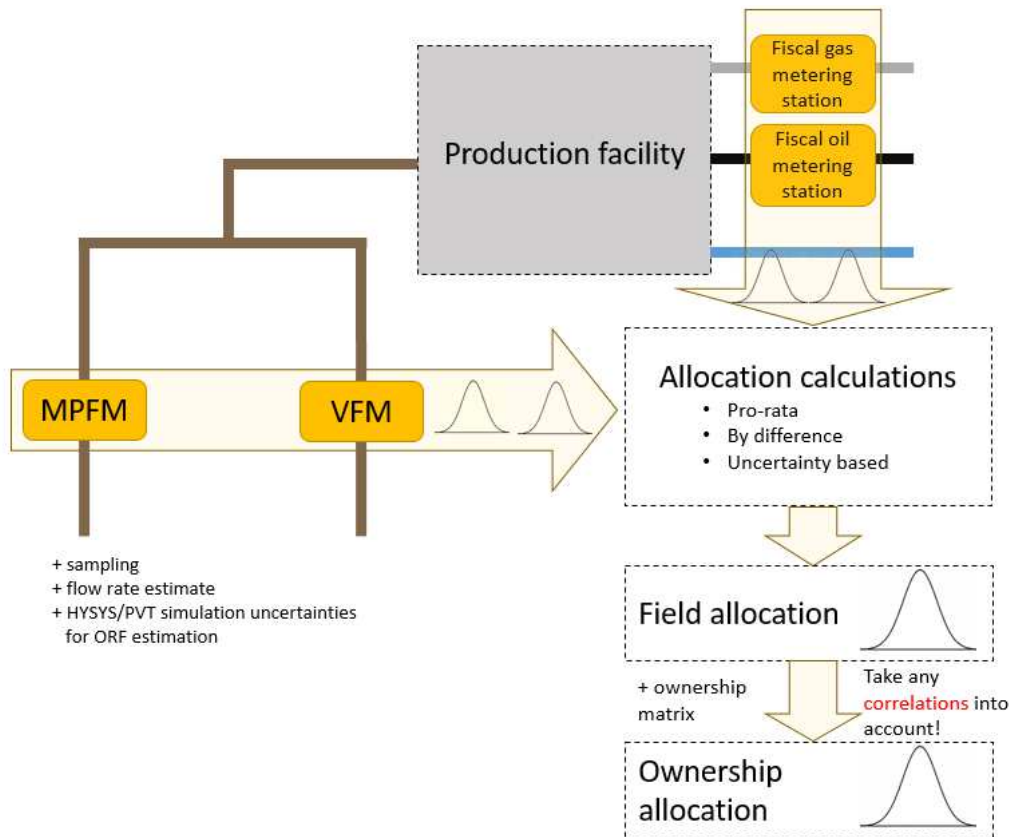[1] This is true for a linear system with normal distributions.

Figure 5: Illustration of the numerical Monte Carlo based framework applied for analysis of multi-field configurations in this paper. This simple setup includes one multiphase metering station (MPFM), one virtual flow metering station (VFM) in addition to export oil and gas metering stations and a production facility. ORF is short for Oil Recovery Factor and specifies expected oil fraction of the total hydrocarbon mass at the output of the production facility. The measurement setup is chosen for illustration purposes only.
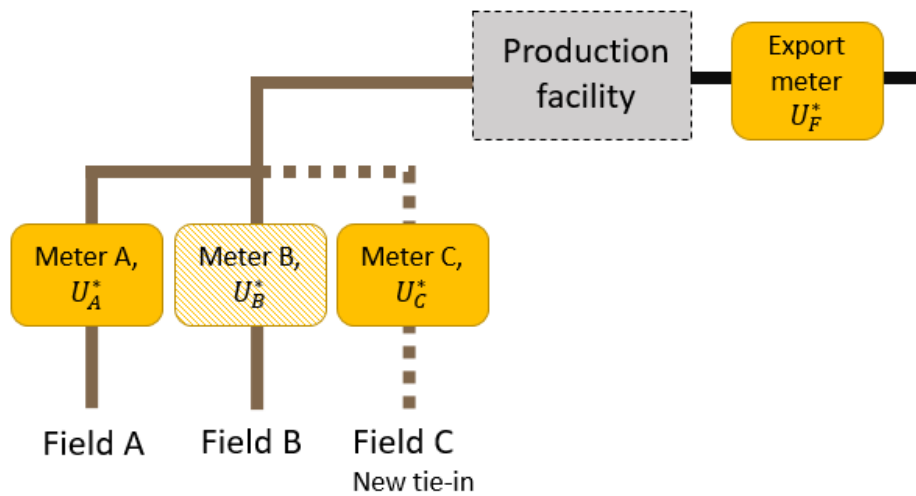
4.5   Simple Case

Our first example is a simple allocation system that originally consists of two hydrocarbon sources, Field A and Field B, that are commingled before processing. Field A has metering station with the specified relative uncertainty U_A^*. Field B is not measured separately. The commingled stream is processed and separated in a production facility before the separated oil and gas streams are measured by single-phase export meters. The amount of hydrocarbons measured by the export meters is allocated by difference to the individual fields and owners.

A new tie-in, Field C, is planned to connect and share the production facility. The new tie-in will have a separate metering station with a specified relative metering uncertainty U_C^*.

As Field C is connected, the exposure to economic risk will change for the fields A and B and thus for the owners of Field A and B. Two options are considered for Field B after Field C is connected as illustrated in Figure 6:

- Continue with the same metering setup and apply by-difference allocation
- Install a new metering station at Field B and convert to pro rata allocation

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Figure 6: Illustration of simple case setup with fields A and B and the new tie-in, Field C. After the new tie-in two options are considered for Field B: 1) Continue with the same metering setup and apply by-difference allocation or 2) Install a new metering station and convert to pro rata allocation.

In order to make the decision as to whether or not a metering station should be installed at Field B, it is useful to investigate how the economic risk changes for Field A and B and the owners of these fields as a consequence of the new tie-in. It is important to do so in a proper manner in order to have solid decision support in evaluating the options for Field B. Here it is worth mentioning that the decisions made for Field B regarding metering setup will most likely affect all the owners of Field A, B and C regardless of whether they are shareholders in fields B or not.

The production profile for each field is modelled according to [5] and are shown in Figure 7 for the fields A, B and C. The two original fields have a production profile such that peak production is 20 million and 360 million tons/year for fields A and B, respectively. The tie-in ratio (Field C) is based on an estimate of total exploitable resources amounting to 50 billion tons. It is drilled a total of 15 wells with a capacity of 50 million tons each, and the field is put in production when eight of them is completed. The remaining wells are completed within three years.

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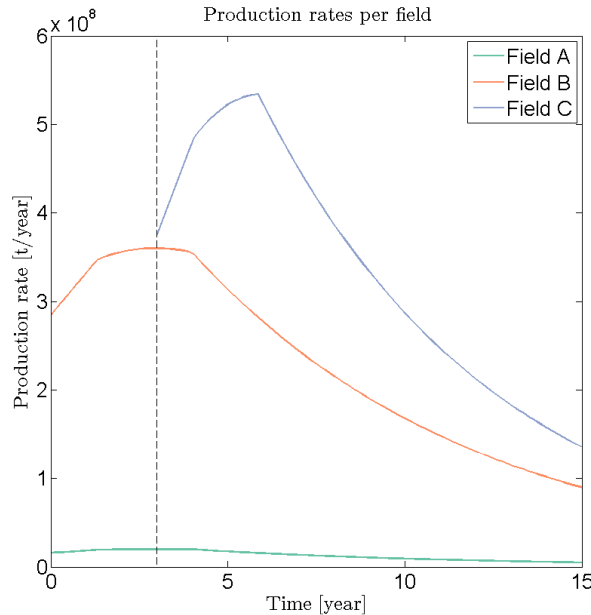
Figure 7: Production rates of the fields A and B and the new tie-in, Field C, used in this example. The dashed vertical line indicates the start-up time for Field C.

We consider five different scenarios. In the first scenario no metering station is installed at Field B and the allocation is performed by difference. In the remaining scenarios, a metering station is installed at Field B and allocation is performed using the pro rata allocation principle. The relative expanded uncertainties of the metering station installed on stream B for the different scenarios are 1%, 5%, 10% and 15% percent. The relative expanded uncertainty of the export station is set to 0.25% while the metering stations at A and C have a 5% relative expanded uncertainty. The metering station uncertainties will be dependent on both the specified uncertainty of the specific meter as well as the chosen calibration and maintenance scheme.

Uncertainty and risk are calculated over a 15 years period using the framework described in [6], based on the production profiles for the three fields shown in Figure 7.

4.5.1 Uncertainty in field allocation

The results of the calculations reported as relative expanded uncertainty per field are shown in **Error! Reference source not found.**. We observe that the transition from the by difference to the pro rata allocation principle proves disadvantageous for the allocation uncertainty of Field A, regardless of the quality of the metering station installed to measure stream B. The allocation uncertainty of Field B, on the other hand, clearly benefits from the transition in all cases but case 5 (i.e. 15 % uncertainty). As a matter of fact, in this particular example the allocation uncertainty for Field B is worse than if using by difference allocation. This illustrates that installing additional metering stations does not necessarily improve the allocation uncertainty, neither for the measured stream, nor for others. Like Field A, the allocation uncertainty in Field C, i.e. the tie in, is also effected by the choice of metering station on stream B, but unlike for Field A, the effect may be beneficial compared with a by difference approach (1 % and 5 %

cases) partly beneficial (10 %) or disadvantageous (and 15 % cases), depending on the quality of the installed meter.
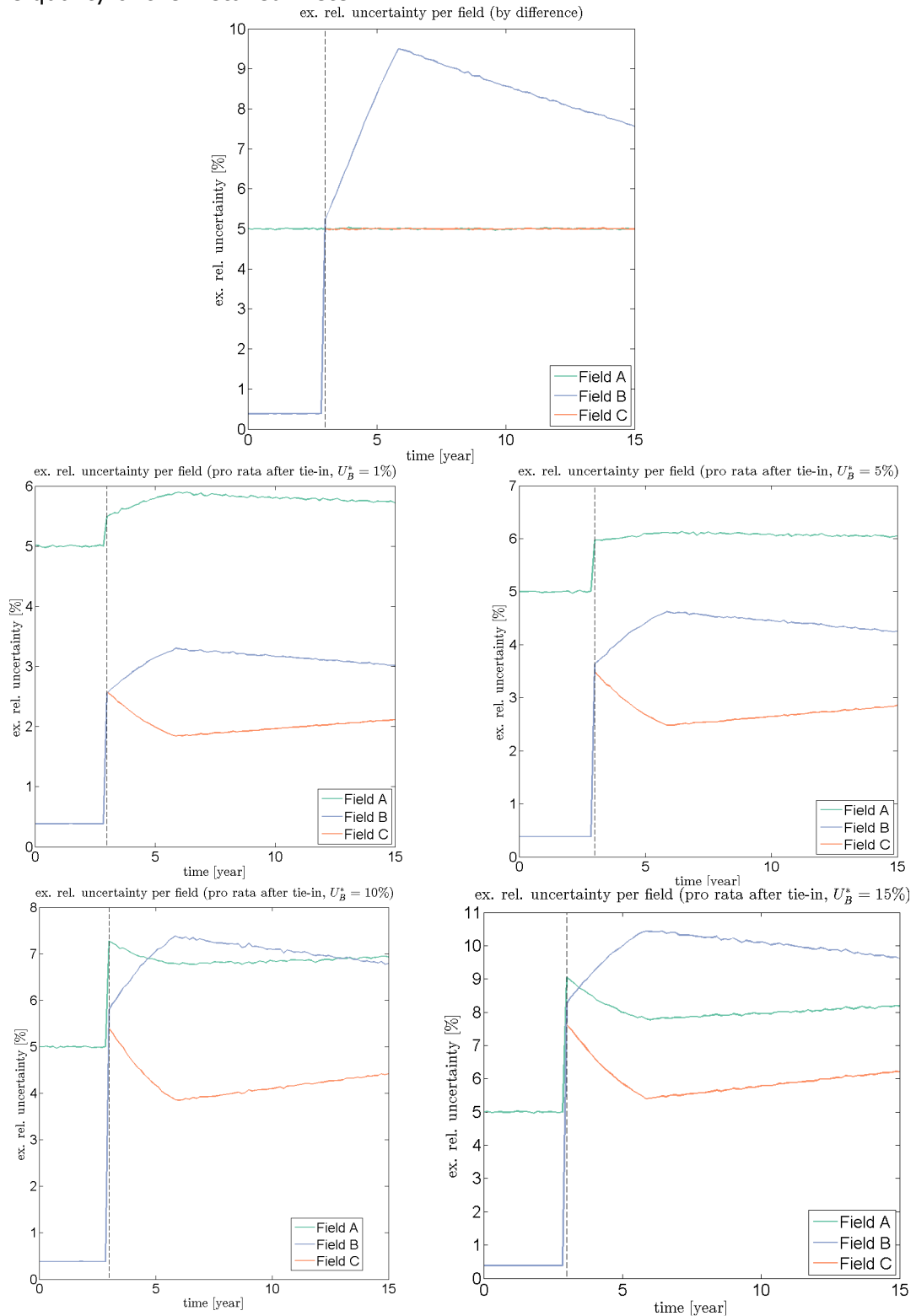
Figure 8: Development of relative expanded uncertainty per field over life time. The top panel gives the uncertainty using by difference allocation after the tie in, while the remaining four describe the uncertainty using pro rata allocation with different uncertainties of the meter installed on stream B.

4.5.2 Uncertainty in ownership allocation

As outlined in the introduction to this example, the underlying business case is the need to decide whether or not to install a metering station on stream B, and, if yes, which uncertainty this metering station ought to have. The installation of a metering station entails an upfront investment (CAPEX) and running cost (OPEX) to which one or several owners of the involved fields need to commit. We assume a fragmented ownership for the fields A, B and C as shown in Table 1 and shall investigate the case from the different owners' point of view. Note that for Field B there are additional owners, that are not included in this discussion. Owner 1 owns the majority of a marginally contributing source (Field A) while Owner 2 holds larger shares in the main source of the original fields (Field B), while Owner 3 controls the tie in, estimated to produce more than the other two fields.

Table 1: Ownership matrix illustrating the ownership for Owner 1, Owner 2 and Owner 3 in the fields A, B and C.

	Field A	Field B	Field C
Owner 1	75 %		
Owner 2	25 %	50 %	
Owner 3			100 %

We recall from the plots in the previous section that Field B experiences a quite dramatic increase in allocation uncertainty due to the tie in. Hence, it may seem reasonable to assume that Owner 2 is the party that would benefit the most from the installation of an additional metering station. Converting the relative uncertainty to economic risk using Equation (1) shows, however, that Owner 3 is most exposed to risk and would have the largest risk reduction (cf. Figure 9 for a comparison of by difference and pro rata with $U_B^* = 10\%$) if a metering station is to be installed. Hence, Owner 3 may be interested in contributing to the investment.

Owner 1, on the other hand, will experience an increased risk if a metering station is installed and may therefore be reluctant to accept such a modification. The total value of this risk is, however, so small compared to the possible benefits of the other owners that compensating Owner 1 may be a reasonable option.

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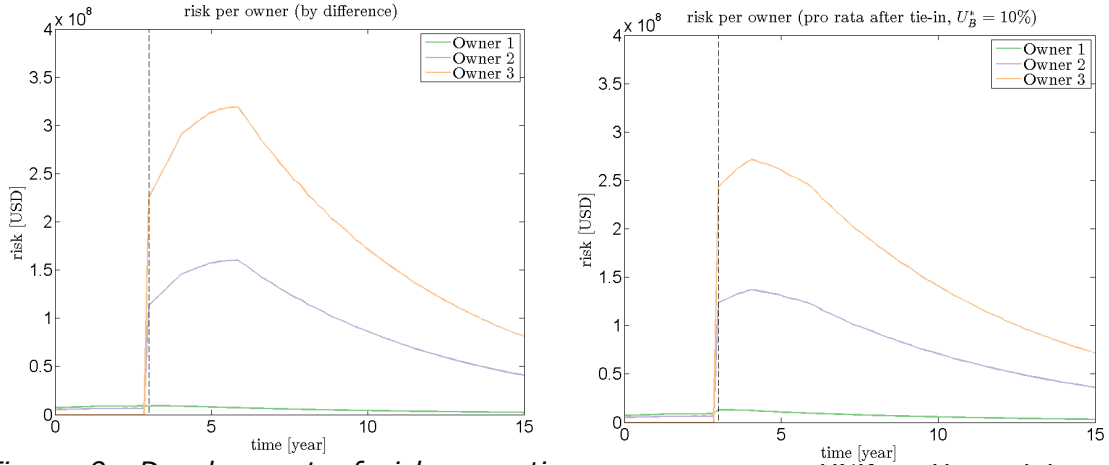
Figure 9: Development of risk over time per owner in USD. The relative expanded uncertainty of metering station B is set to 10% in the left plot. An oil price of 60 USD is assumed.

From Figure 9 it becomes apparent that also the temporal evolution of the risk ("peak risk" in year 7 with by difference allocation vs. "peak risk" in year 4 with pro rata, and similar risk values for the three owners in year 15) changes depending on the chosen solution and the metering solutions need to be assessed from a lifetime perspective. Figure 10 shows the accumulated risk for each owner after 15 years,. The difference in risk between different metering solutions is a quantifiable benefit of one solution over the other and may as such be used in the decision making process. In order to make a fair assessment it is important to keep in mind at this point that the CAPEX and OPEX of different metering stations will vary depending on the specifications of the metering station and the maintenance and calibration scheme chosen. This risk calculation also prepares the foundation for full cost-benefit analysis including CAPEX and OPEX as described in [6] and can be extended to include other types of risk as in [7].

We have chosen not to include the full cost-benefit analysis in this paper as the CAPEX and OPEX may vary significantly from one setup to another, nor is it essential for the main results of this paper.

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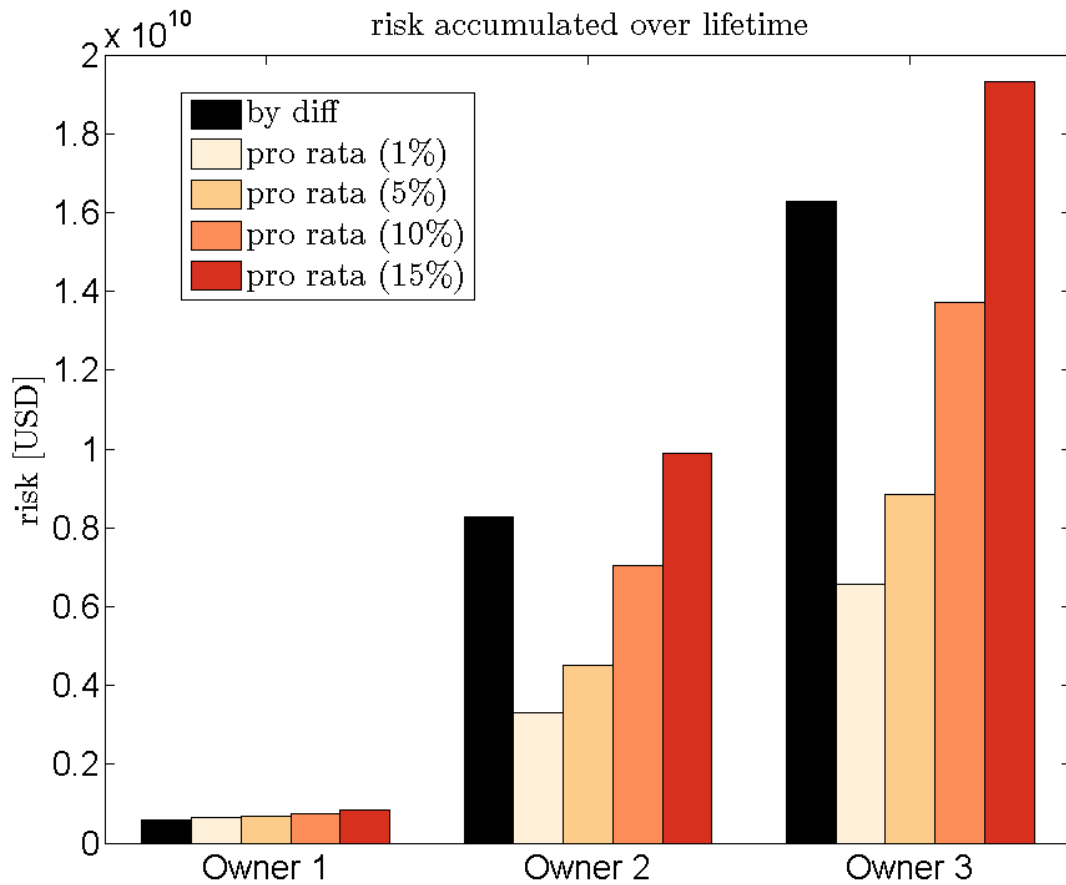
Figure 10: Risk associated with allocation uncertainty per owner accumulated over lifetime with different metering setups. The relative expanded uncertainty for the export metering station is set to 0.25 % (95 % confidence interval) in all cases. An oil price of 60 USD per barrel is assumed. The uncertainty numbers and oil price used in the different scenarios are chosen for illustration purposes only.

4.6   Realistic Example System Based on Industry Projects

In order to illustrate the real usefulness of our analysis framework we present results from a realistic example system based on industry projects. We show how an uncertainty analysis combined with a risk analysis may provide valuable insight into the exposed economic risk for each owner due to misallocation. Note that the example setup presented in this section is modified from the real industry setup and that all numbers are example numbers in order to anonymize the data.

A simplified sketch of the example setup is shown in Figure 11. There are two existing fields: Field A is processed through a 1st stage separator before the oil and gas streams are measured by single phase meters and then passed on to a production facility. Field B is not measured separately before being processed in the production facility. At the output of the production facility the separated streams of oil and gas are measured by export meters. The oil and gas measured by this export meter is allocated by difference to the individual fields A and B, and the respective owners. Samples are taken regularly at the inlet of each field, as well as at the export station. The allocation is performed on component level and

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HYSYS simulations are performed in order to estimate the component oil recovery factors, including their uncertainty. There are also facilities for gas lift and water injection not shown in this simplified setup.

The new tie in, Field C, is planned to connect and share the production facility. The new tie-in is planned to have a dedicated metering station based on a multiphase meter and sampling.

The shareholders in the system are concerned about how this new tie-in will affect their exposure to economic loss. Should they take the cost of installing a separate metering station at Field B and convert to pro rata allocation? Who should be committed to take part in this investment? What is the correct procedure to uncover the exposure to economic loss for the owners in these fields?
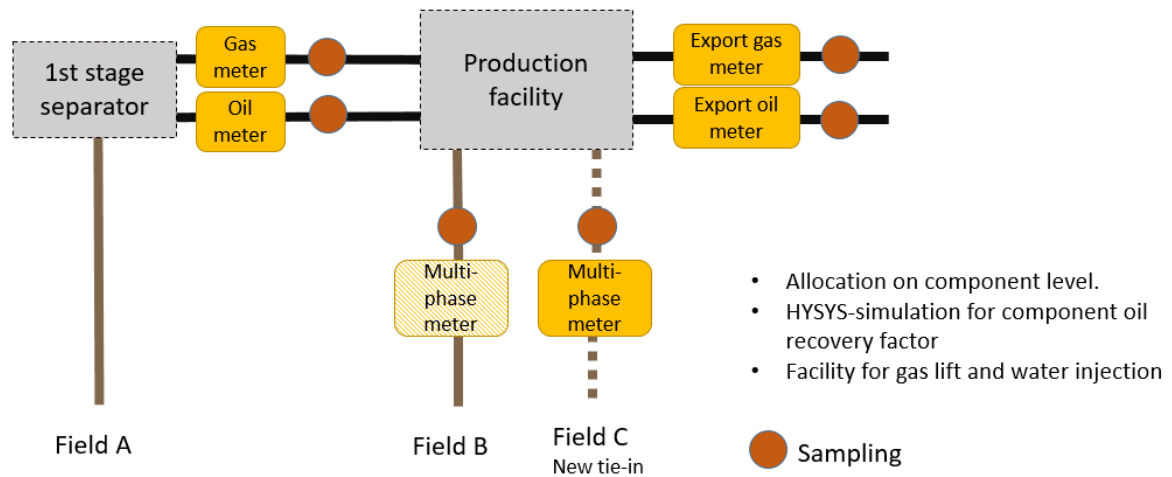

*Figure 11: **Real-life example:** 2 existing fields, one new tie-in. 1st stage separators and multiphase flow meters.*

In order to answer these important questions, an uncertainty analysis combined with a risk analysis are carried out. We assume the same ownership distribution as in the previous section, given in Table 1. The production rates follow the same profiles as in the previous examples besides that the rates of Field A are increased by a factor of five. Figure 11 gives the summary of the temporal evolution of the relative expanded uncertainty of the field allocation for the two different scenarios. The lighter colours represent pro rata allocation, the darker by difference.

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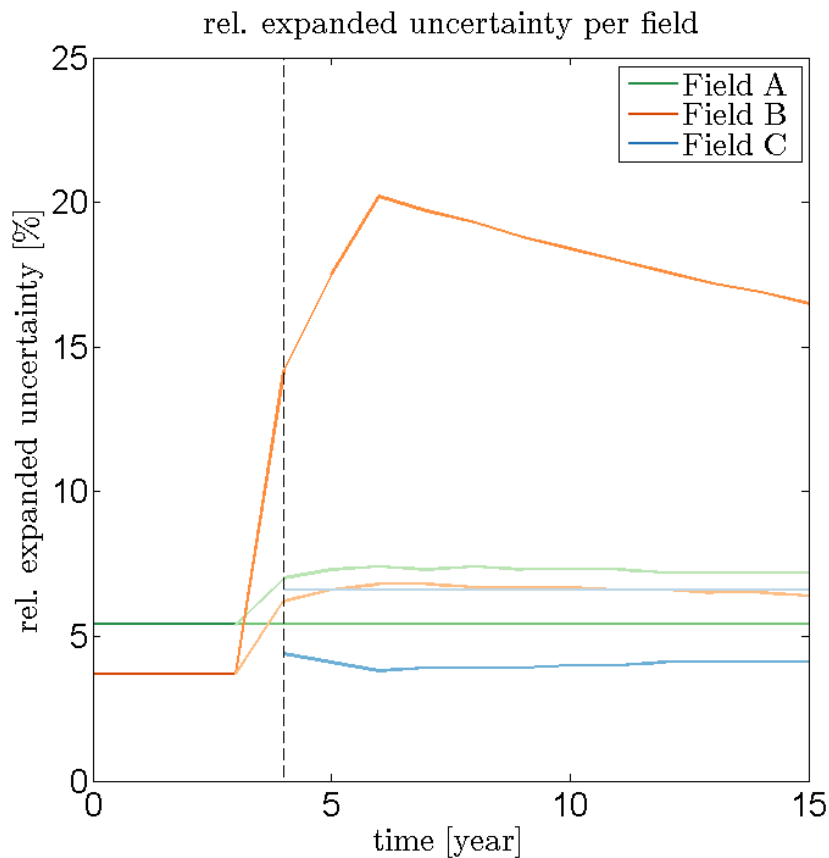
Figure 12: Temporal evolution of the relative expanded allocation uncertainty per field. The dashed vertical line indicates the start of production of Field C. The two different scenarios for the allocation system (continuing with by difference allocation or switching to pro rata) are indicated with different shades of the colour associated to the respective field, the darker shade represents by difference allocation, the lighter pro rata.

In this example we will focus on the effects of correlation between the field allocated quantities in ownership allocation. To this end, we compare the lifetime risk for each owner calculated using correct ownership uncertainty to the results of the same calculations based on Equation (2). The results from this analysis are shown in Table 2. The first column of the table denotes the allocation principle applied and the different owners, while columns 2 and 3 show the exposure to risk accumulated over field lifetime (15 years) correctly accounting for correlations (column 2) or using the erroneous Equation (2). The rightmost column gives the difference between the two calculations. The relative expanded uncertainties for the metering stations A and B (if any), and C is set to 5 % (95% confidence interval) while the relative expanded uncertainty for the export metering station is set to 0.25 % (95 % confidence interval) in all cases. An oil price of 60 USD per barrel is assumed. Note that correlations only affect owners holding shares in several sources, i.e. Owner 2 in this example.

We see that the change in risk is, like in the previous example, dominated by the choice of allocation principle, but the effect of correlations between allocated streams is only one order of magnitude smaller and thus far from negligible. Depending on the allocation principle, using the ad hoc method following Equation (2) results in an overestimation of the risk exposure between 41 and 46 million

dollars over the field lifetime. Furthermore, neglecting correlation yields also a slight overestimation of the benefit for Owner 2 in switching allocation principle, approximately 4.7 million dollars. While this figure may not seem dramatic compared to the overall risk, this is still in the order of magnitude of the total cost of a metering station.

Table 2: Parameters for the two different scenarios considered in the realistic example system. The uncertainty numbers and oil price used in the different scenarios are chosen for illustration purposes only.

		Exposure to risk [USD], accumulated over lifetime		
		with correlations	using Eq. (2)	difference
By diff	Owner 1	115 702 379	115 702 379	0
	Owner 2	544 899 752	590 653 852	45 754 100
	Owner 3	835 761 210	835 761 210	0
Pro rata	Owner 1	141 161 739	141 161 739	0
	Owner 2	246 653 591	287 723 559	41 069 968
	Owner 3	509 024 384	509 024 384	0

6 SUMMARY AND CONCLUSIONS

This paper describes the calculation of field and ownership allocation uncertainty for realistic measurement setups and allocation scenarios in a multi-field setting based on industrial projects. Furthermore, the exposure to losses due to misallocation is calculated and discussed for different metering setups.

Beyond illustrating exposed economic risk for each owner due to misallocation through realistic example systems, this paper has three main messages:

- The field allocation uncertainty will in many cases differ significantly from the individual metering station uncertainties (dependent on the system setup).
- In most real life setups, it is not intuitive to decide which owner(s) that are most exposed to economic loss due to misallocation.
- It is mandatory to take into account the correlation between the uncertainties in the field-allocated streams in order to estimate the owner allocation uncertainty correctly.

7 NOTATION

$U^*(x)$	Relative expanded uncertainty of a quantity x
$U(x)$	Absolute expanded uncertainty of a quantity x
$F_{field\,y}^{owner\,x}$	Ownership fraction for owner x in field y
R	Exposure to lost revenue
V	Value per unit of relevant quantity
$\bar{x}$	Average of quantity x
k	Coverage factor
$r_{A,B}$	Correlation coefficient between parameters A and B

CAPEX   Capital expenditure or capital expense
OPEX   Operating expenditure or operational expense

8   REFERENCES

[1] ISO/IEC Guide 93-3:2008/Supplement 1, «Propagation of distributions using a Monte Carlo method,» ISO/IEC, Geneva, 2008.

[2] T. Aven, Pålitelighets- og risikoanalyse, Oslo: Universitetsforlaget, 1991.

[3] P. Stockton, «Cost Benefit Analyses in the Design of Allocation Systems,» i *27th International North Sea Flow Measurement Workshop*, 2009.

[4] ISO/IEC Guide 93-3:2008, , «Uncertainty of measurement - part 3: Guide to the expression of uncertainty in measurement (GUM:1995),» ISO/IEC, Geneva, 2008.

[5] Stein W. Wallace, Carsten Helgesen and Arild Nystad, «Generating production profiles for an oil field,» *Mathematical modelling,* vol. 8, pp. 681 - 686, 1987.

[6] A. Pobitzer, A. M. Skålvik og R. N. Bjørk, «Allocation System Setup Optimization in a Cost-Benefit Perspective,» *Journal of Petroleum Science and Engineering,* vol. In press, p. http://dx.doi.org/10.1016/j.petrol.2016.08.025, 2016.

[7] Astrid Marie Skålvik, Ranveig Nygaard Bjørk, Kjell-Eivind Frøysa and Camilla Sætre, «A new methodology for cost-benefit-risk analysis of oil metering lay-outs,» i *33rd International North Sea Flow Measurement Workshop*, Tønsberg, 2015.