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Application of Data Validation and Reconciliation to Production Allocation

Amin Amin, Letton Hall Group
Robert A. Webb, Letton Hall Group
Boris Kalitventzeff, Belsim SA
Georges De Vos, Belsim SA

1 INTRODUCTION

Generally, upstream oil and gas export measurements are made on separated and depressurized bulk oil and gas flow streams collected from a group of wells. In depressurized conditions, where phase separation can be ensured, single phase measurements can be made with the best possible accuracy. These measurements follow measurement standards and recommended practices, such as from the API MPMS, Chapter 20, Section 1.

Wherever export production contains fluids from more than one producer (or unique ownership group, whether it is for one well or several), there must be an equitable distribution of the production export to each and every contributing producer. The allocation process serves to determine in the most fair manner the quantities of oil and gas produced, flared, consumed for fuel, or otherwise spent out of the total export over a given time period for each contributing producer. The allocation process starts at the end of upstream production, from the point of custody transfer to the midstream transporter, and works back upstream to the source of production, the well. In determining each producer's fair share of the export production, the resulting revenues and costs, such as production handling service fees, royalties and other costs, can be completely resolved.

The allocation process of quantifying the volume or mass of fluids produced from each well applies similarly to non-fiscal activities, such as the management of well performance, process facility operations, and reservoir recovery. While these applications are also important, they generally do not involve the resolution of inter-company financial transactions in accordance with an agreement. The elements of upstream metering and allocation carried out for fiscal allocation often encompass most of the needs for well or fluid allocation; however, the unique measurement requirements of reservoir and production management should be considered separately in order to get a complete set of metering and allocation requirements for all end uses of the flow measurement data.

Finally, if the allocation fully serves its purpose, it should be auditable and defensible. A good allocation minimizes disputes between partners in a production agreement.

In practice, how is this achieved? Unmixing the mixed streams of hydrocarbons from different wells, zones and fields is not straightforward. It can be downright challenging, and it certainly can be done in different ways leading to different outcomes, which leads back to the possibility of dispute. A good allocation, therefore, is one that is agreeable to all parties involved.

For each producer to get a consistently good, equitable allocation, it requires:

1. a written agreement that defines the objectives and methods of the allocation
2. a metering system that can deliver the required flow and other measurements
3. an auditable, independent execution of the allocation process

As with many physical phenomena, a deterministic approach to defining the outcome of certain pre-established procedures and agreements is not always realistic. Errors and uncertainties in measurements, processes, and models, visible and hidden are also critical to the allocation process requiring attention and understanding by all parties involved, the producers and regulator alike. Identifying and understanding the sources of measurements errors is a necessary step to minimize their impact on allocation.

The risk of revenue loss by any of the parties, big or small due to ill-defined statistical factors will strongly reflect on the sense of fairness felt by everyone. Such situation can trigger with individuals a sense of unfairness as they learn that the production allocated to their lease is deemed less certain than the one from next door despite the fact that they both use the same equipment to measure production! Can this knowledge be used to mitigate "unfairness" and reduce the exposure faced by producers and regulators in the execution of their duties?

Through the study of simulated production scenarios the paper highlights ways to detect and deal with errant data in production allocation data sets. It also proposes and evaluates a practical procedure that turns DVR error-qualifiable production data into allocated quantities the same way traditional PSM systems are used in production allocation. The difference is that in the latter approach the data qualification for potential data bias or imprecision is not integrated in the allocation process leaving room for production misallocation risks.

The evaluated approach is based on maximizing the use of all available process information (devices and fluids) in an attempt to "vote out" erroneous measurements once identified. Results are evaluated with and without the erroneous data in moderate cases where measurements cannot be replaced for cost or operational reasons.

The Data Validation and Reconciliation (DVR), as the name implies, is evaluated for measurement error identification (surveillance functionality), and for its ability to make production estimates that qualify as allocated quantities of a relatively complex multi-tiered commingled production system. The current work builds on earlier effort that aimed at studying the use of measurement uncertainty in production allocation; Pro-rata, Uncertainty-based, and DVR-based methodologies [1].

DVR background and basic theory are first reviewed then followed by a review of the steps employed to perform traditional proportional allocation of volumetric quantities using Process Simulation Modeling (PSM). A PSM-DVR approach to allocation is proposed in the paper and tested by comparing the results to the "True Values" of a Reference simulation and to the results obtained from the PSM-Proportional Allocation methodology. However before performing allocation calculations, various production scenarios are simulated with various types of measurement and fluids property errors to test DVR's surveillance capabilities. Proportional and DVR based allocation is carried out with and without errors and with varying amount of information to examine the robustness of allocation answers of each allocation methodology. The results are compared with the process "True Values".

The paper continues in summarizing practical considerations and recommendations on the use of DVR in surveillance and/or allocation applications. It is also shown that if DVR-based allocation is not adopted for commercial or contractual reasons, other allocation methodologies will continue to benefit from a parallel DVR implementation for surveillance applications. Moreover, while the determination of measurements uncertainties has direct relevance to monetary arrangements if DVR is used for allocation, the constraints in quantifying the uncertainty values can be relaxed if the DVR process is used for surveillance only.

2 DATA VALIDATION AND RECONCILIATION (DVR)

2.1 Background [2]

Industrial process data validation and reconciliation, (DVR), is a technology that uses process information and mathematical methods in order to automatically correct measurements in industrial processes. The use of DVR allows for extracting accurate and reliable information about the state of industry processes from raw measurement data and produces a single consistent set of data representing the most likely process operation.

DVR has become more and more important due to industrial processes that are becoming more and more complex with applications aiming at closing material balances in production processes where raw measurements were available for all variables. At the same time the problem of gross error identification and elimination has been addressed. Later, unmeasured variables were taken into account and the process matured by considering general nonlinear equation systems coming from thermodynamic models. Quasi steady state dynamics for filtering and simultaneous parameter estimation over time were introduced by Stanley and Mah.[3] Dynamic DVR was formulated as a nonlinear optimization problem by Liebman et al. in 1992.[4] followed by the use of Interior Point SQP by Kalitventzeff et al. for large-scale process optimization in 1996.[5]

Data reconciliation is a technique that aims at correcting measurement errors that are due to measurement noise, i.e. random errors. From a statistical point of view the main assumption is that no systematic errors exist in the set of measurements, since they may bias the reconciliation results and reduce the robustness of the reconciliation. However, systematic errors will be flagged if they are the cause for measurements excessive deviation from the "expected" values that best balance the system

DVR finds application mainly in industry sectors where either measurements are not accurate or even non-existing, like for example in the upstream sector where flow meters are difficult or expensive to position; or where accurate data is of high importance, for example for security reasons in nuclear power plants. Another field of application is performance and process monitoring in oil refining or in the chemical industry.

The application of DVR to production allocation for fiscal or reservoir management received increased attention in past few years albeit for specific cases; Ref [6] used the basic linear solving algorithms to arrive at the formulation of Uncertainty Based Allocation methodology of developed in [7] and [8], while Ref [9] applied DVR error minimization technique to take advantage of the field's lower GOR uncertainty to improve the production allocation of commingled subsea fields/wells. On the other side, Ref [1] took a more general approach by evaluating DVR in the context of using measurement uncertainty with different allocation methodologies.

As DVR enables to calculate estimates even for unmeasured variables in a reliable way, the German Engineering Society (VDI Gesellschaft Energie und Umwelt) has accepted the technology of DVR as a means to replace expensive sensors in the nuclear power industry (VDI norm 2048) [10].

2.2 Basic Theory

Given n measurements y_i, data reconciliation can mathematically be expressed as an optimization problem of the following form:

$$\min \sum_{i=1}^{n} \left(\frac{y_i^* - y_i}{\sigma_i} \right)^2 \qquad (1)$$

Subject to $F(x, y) = 0$

where y_i^* is the reconciled (allocated) value of measurement y_i, and x_j is the unmeasured variable $(j = 1\ to\ m)$.

σ_i is the absolute uncertainty (standard deviation) of measurement y_i and $F(x, y) = 0$ are the r process equality constraints. (Figure 1)

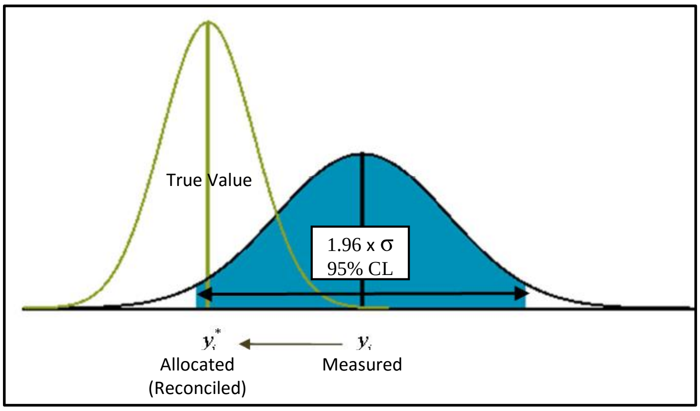


Figure 1 Illustration of Measurement and Reconciled Values with their Uncertainties Assuming Gaussian Distributions

The term $\left(\frac{y_i^* - y_i}{\sigma_i} \right)^2$ is called the penalty of measurement i. The objective function is the sum of the penalties.

In other words, one wants to minimize the overall correction (measured in the least squares term) that is needed in order to satisfy the system constraints (mass, energy, component balances and phase equilibrium at each node). Additionally, each least squares term is weighted by the standard deviation of the corresponding measurement. In this formulation, both measurement bias and uncertainty (precision) are factored in the estimation of reconciled (validated) quantities.

Data reconciliation relies strongly on the concept of redundancy to correct the measurements as little as possible in order to satisfy the process constraints. Redundancy arises from combining sensor data with the model (algebraic constraints such as mass balance).

Redundancy can be used as a source of information to cross-check and correct the measurements y_i and increase their accuracy and precision. Further, the data reconciliation problem also includes unmeasured variables x_j. Based on information redundancy, estimates for these unmeasured variables (ex. missing flow measurement) can be calculated along with their accuracies. In industrial processes these unmeasured variables that data reconciliation provides are referred to as soft sensors or virtual sensors, where hardware sensors are not installed.

An important feature of DVR is results validation and gross error detection. Result validation may include statistical tests to validate the reliability of the reconciled values, by checking whether gross errors exist in the set of measured values. These tests can be for example:

1. The Global test of the entire system requiring that the summed penalties for a given number of constraints r should be less than the Chi-squared test criteria defined in VDI norm 2048 [10].
2. The Individual test compares each penalty term in the objective function with the critical values of the measurement's normal distribution. If the i-th penalty term is outside the 95% confidence interval of the normal distribution, then there is reason to believe that this measurement has a gross error as illustrated in Figure 1.

Advanced data validation and reconciliation is an integrated approach of combining data reconciliation and data validation techniques, which is characterized by:

1. Complex models incorporating besides mass balances also thermodynamics, momentum balances, and phase equilibria constraints etc. This is particularly applicable to complex allocation schemes where a Process Simulation Model (PSM) is used to account for mass transfer between phases in a commingled stream.
2. Gross error remediation techniques to ensure meaningfulness of the reconciled values in the presence of moderate biases.
3. Robust algorithms for solving the reconciliation problem.

2.3 DVR-based Production Allocation

In production allocation, the DVR approach differs from traditional methods by fully accounting for the system uncertainties associated with measurement devices, process parameters or fluids properties, and by allowing system redundancy to improve the accuracy and precision of the allocated quantities. This ensures that the allocated quantities are estimated in accordance with the physical principles/laws and constraints of the producing system. The approach can therefore be judged as more equitable where the allocated quantities are qualified by their degree of agreement with the original measurements (or lack thereof) in the form of global and individual penalties that can be monitored and quantified.

In production allocation schemes, where the balancing of multiple nodes may be required along the production path from subsea to sales, the minimization of Eq.(1) results in a series of equations that are solved simultaneously for the entire system to determine the adjustments vector $\boldsymbol{v}$. The adjustment is then added to the measurements vector $\boldsymbol{y}$ in order to calculate the reconciled/allocated value $\boldsymbol{y}^*$ (Eq.(2):

$$\boldsymbol{y}^* = \boldsymbol{y} + \boldsymbol{v} \qquad (2)$$

In the majority of allocation cases involving straightforward mass or energy balances, the calculation is reduced to linear algebraic matrix operations solvable using spread sheets embedded functionalities. Such algorithm was incorporated in an allocation tool to perform this type of calculations.

On the other hand, more elaborate allocation schemes involving phase equilibrium calculations (PSM) will require the use of DVR software with built-in thermodynamics package and non-linear solver to allow for the simultaneous iterative solving of system's equations. A procedure to combine PSM and DVR methodologies is described in the following sections. The results are compared to the traditional PSM-Pro-rata approach.

3 FORMULATION OF COMPLEX ALLOCATION

3.1 Process Simulation Model (PSM)

Differences in the composition of the inlet streams and their respective process conditions will have an impact on the allocation due to material transfer between the commingled streams. Therefore, a Process Simulation Model (PSM) is used. The PSM calculates theoretical produced oil and gas volumes as well as Gas Energy Content for each separator(s) relative to the measured export quantities.

Commercial simulation packages are used in combination with an Equation of State (EOS), as provided in the PSM software, to generate the phase behavior and fluid properties and output results. The EOS is tuned to actual lab experiments for improved results.

Forward calculations are performed using the streams flowrates and fluid composition as inputs. Such inputs are obtained from “Allocation” single phase flow metering devices after separation or from physical or virtual multiphase flowmeters, and from fluids samples.

Additional measurements/samples are also performed at the Export/Sales point and in-between at various points/nodes in the process facility or production path. The Export measurements are usually custody transfer quality measurements of the stabilized hydrocarbon streams and are of high accuracy and precision.

For the purpose of this study, only the liquid streams (oil) are considered and shown in the following PFD diagram. The same treatment can also be applied to gas streams including liquid recovery from compression and vapor recovery processes.

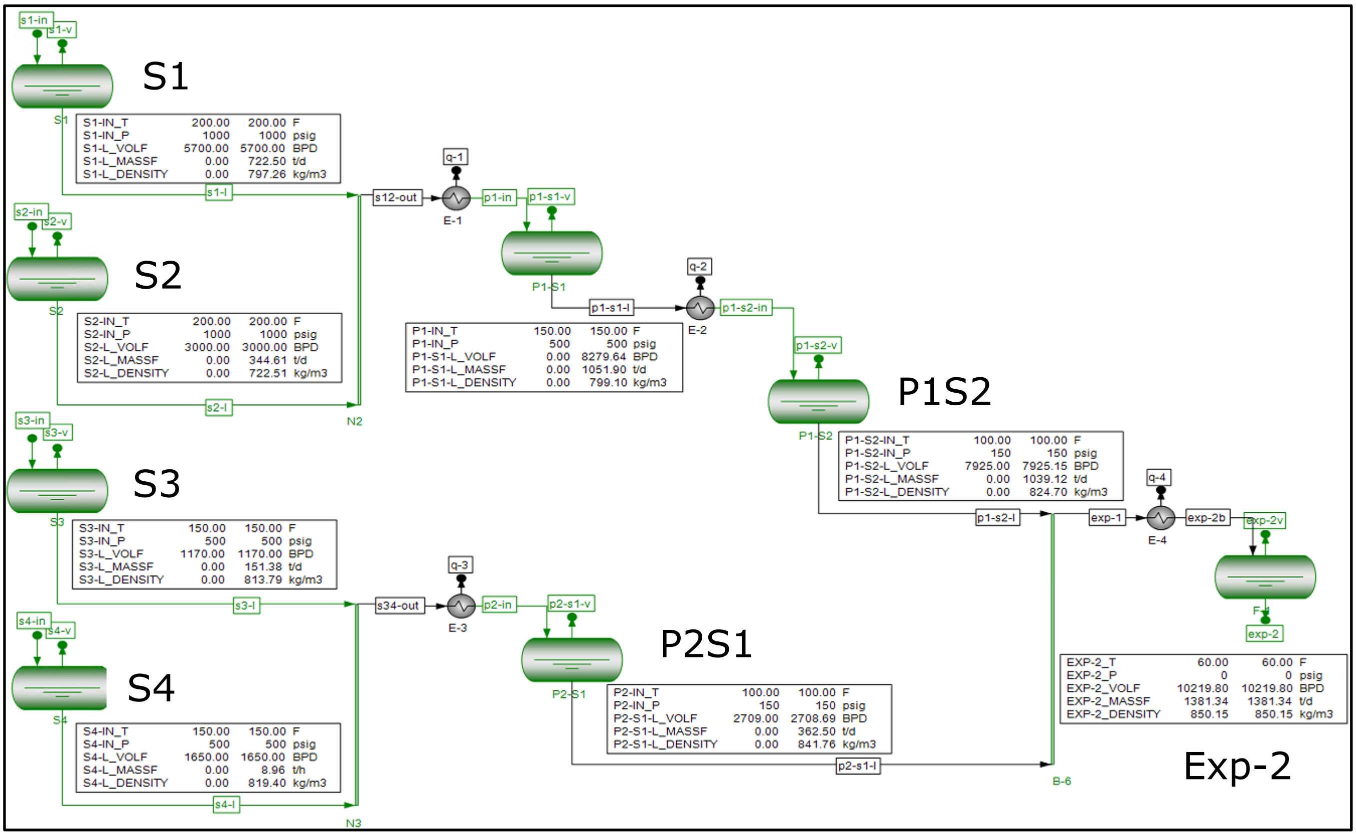


Figure 2 Reference oil process, 4 Inlet Separators, 2 Production Trains and Sales Meter

3.2 Proportional Allocation with PSM - The Traditional Way

Due to the differences in the fluid compositions, pressures, and temperatures, the use of a PSM is required. The PSM is used in multiple steps to allocate production measured and sold at the export meter to each of the inlet separators. The allocation is performed on volume quantities basis and is critically impacted by the phase transfer or inter-molecular mixing taking place between the streams as they travel from the inlet to the export point.

The common industry practice is to first determine the PSM results at the export point conditions when all inputs from the separator streams are included in the simulation (Combined PSM Run) [11]. The estimate of what a separator has contributed is the result of all separator streams simulated except one separator's streams (Exception PSM Runs). The Exception PSM run determines the Theoretical Volumes for the separator not being simulated (Figure 3). To balance the system volumetrically, the Volume Imbalance due to the difference between the Export meter and the sum of all Theoretical Volumes, is added or subtracted from each stream in pro-rata of the its Theoretical Volume.

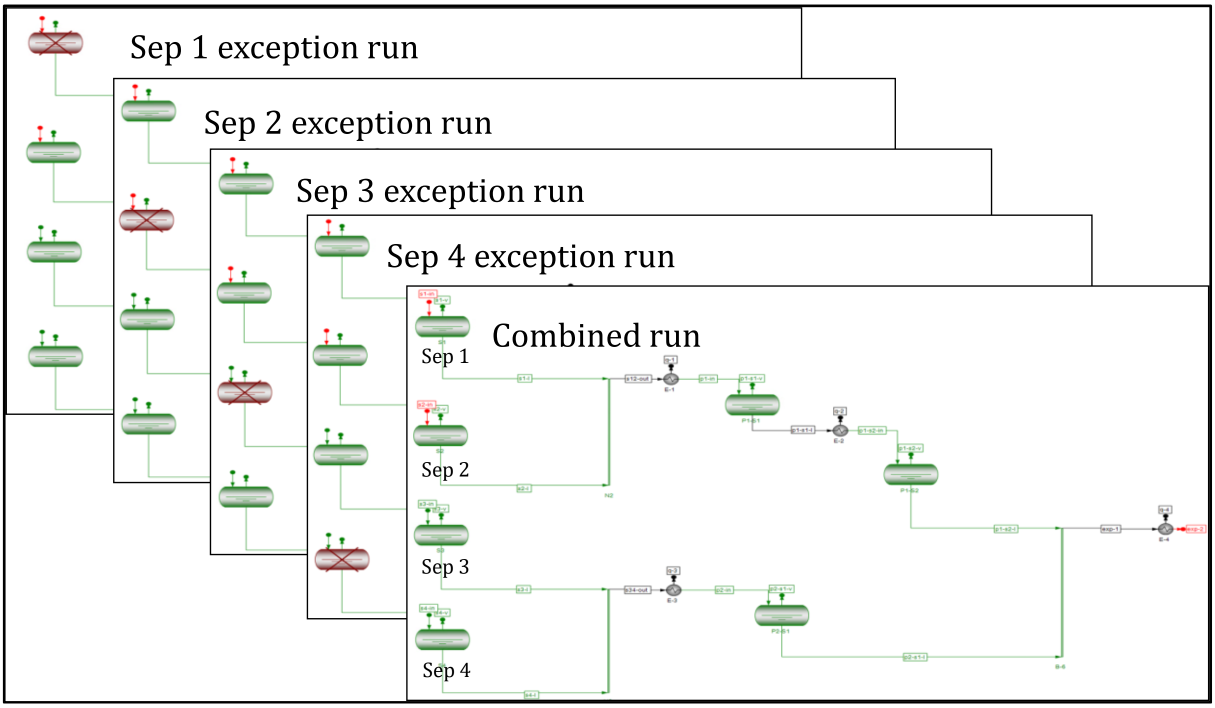


Figure 3 - Illustration of PSM Configuration for Combined and Exception Runs

3.3 Description of the Simulated Process

The process scenario used in the study is typical of a host facility consisting of two production trains, high and intermediate pressures. Two inlet separators (S1, S2 and S3, S4) are used on each train with additional production or bulk separation stages; two intermediate separation stages in the Train1 (P1S1, P1S2) and one (P2S1) in Train2. The mixed stream is taken down to standard or stock tank conditions using one more separation stage before the export point (Exp-2). The process pressure and temperature set conditions are shown underneath each separation vessel on Figure 2.

Allocation meters and fluids samples measurements are available from each inlet separator and at the Export point. The precision of the inlet measurements and samples is in the range of 4%-6% while it is specified at 0.1%-0.2% at the Export meter. In between, flow measurements are also available for each of the trains at P1S2 and P2S1.

These are of intermediate precision considering the relatively stabilized nature of the streams at this point.

While the process layout is mostly typical of a surface production host facility, a very similar layout can also be extended to subsea or subsea/surface production process using a combination of separators and physical or virtual flowmetering systems.

All measurements are performed and reported at the process conditions as is the case with any flowmeter used at the outlet of a separator. The next sections will discuss the procedures used to evaluate and report the flowrates at the Export point conditions (assumed standard conditions in this study).

The hydrocarbon fluids have varying compositions and are typical of deepwater production fields. The fluids characteristics obtained from PVT reports are summarized in the following Table 1:

Table 1 - Main Fluid Parameters of Streams Used in Inlet Separators

Inlet Separator	API°	MW (g/mol)	GOR (scf/stb)	Gas Gravity (Air=1)
S1	26.8	108.0	700	0.704
S2	43.2	28.5	18600	0.784
S3	25.4	174.3	220	1.014
S4	22.5	167.8	230	0.760

Because of the streams' relative distribution, extensive interaction is expected within Train1 and little material transfer between the two trains since they only combine after multiple separation stages at relatively low pressure and temperature.

The composition of the monophasic fluid flashed in each of the inlet separators was reduced for simplicity to N2, CO2, C1 thru C6, C7-12, C12-20, C20-30, C30+. The key properties of the lumped components were available from the PVT reports.

4 COMPARATIVE STUDY

The results of the above proportional allocation procedure with PSM will be evaluated using the process model and calculation method described in previous section.

The software package used in the study has the dual capability of working as pure PSM forward simulator and as a PSM-DVR engine. By switching between the two modes, it is possible to generate two sets of allocation results; from the PSM-Proportional Allocation (PSM-PROP) and from the PSM Validation and Reconciliation (PSM-DVR) methodologies.

Moreover, in this package, the results of the PSM runs are evaluated along with their uncertainties using the uncertainties specified for the input measurements/parameters: flowrates, fluid composition, process instrumentation, etc. The evaluation and use of allocated quantities uncertainties was addressed in [1] and is not repeated in this paper.

In addition, the PSM mode is used to generate a third set of results treated as Reference or True Values; the relative deviations of different allocation methods (PROP or DVR) are evaluated in reference to the True Values. In other instances the True Values determined by this initial simulation run are used as intermediate measurements to assess the impact of added information on the allocation or reconciliation results. This is mostly applicable to the DVR method where intermediate flowrates and Export sample results can be integrated with inlet measurements (new measurement Tags).

The simulated process is a multi-tier allocation process consisting of three allocation nodes. In the absence of measurements at the trains' outlets, P1S2 and P2S1, the entire process is treated as a single tier allocation scheme by performing the Combined and Exception runs using the flow measurements at the inlet and export points. Including the intermediate measurement at the production separators (if available) is a matter of adding the measurement tags in the simulator when running in the PSM-DVR mode. The same cannot be done in PSM mode alone without doing multiple simulation runs and two proportional allocations to balance the system at the P1S2, P2S1, Export node and at the inlet separators nodes for Train1 and Train2. Such practice is not common. Instead a single balancing calculation is performed without making use of the intermediate measurements. Alternatively such measurements can still be used for quality check and measurement performance improvements before allocation calculations.

4.1 Evaluation Procedure and Objectives

A number of cases (production scenarios) were run in the PSM-PROP and PSM-DVR modes where Combined and Exception runs were used to perform production allocation at export meter conditions. Such process was applied to the PSM runs as described before, and to the DVR results. In the case of DVR, the Combined and Exception simulation runs were done using the reconciled estimates obtained from the PSM-DVR mode. No further proration is required because the DVR results have already been balanced during the reconciliation/DVR run. The difference between the Combined and Exception runs are used directly as the allocated volume quantities for each of the inlet streams evaluated at the Export meter conditions and are compared to the PSM-PROP method and the Reference case as will be shown in other parts of the paper.

The analyzed production scenarios are used to assess the performance of the PSM-DVR mode to:

- Detect flow measurement bias
- Detect fluid samples errors (density and composition)
- Evaluate the impact of additional measurements (flowrates and fluid sample information) on the accuracy and precision of reconciled results
- Perform production allocation driven by measurement uncertainty and bias minimization
- Perform comparative evaluations with the traditional PSM-PROP mode and with the Reference "True Values"

4.2 Simulated Reference Case

As noted before, the Reference case is a PSM simulated case using Reference inlet flowrates at metering conditions (Figure 2) and the fluids of Table 1. The simulated data provides the "True Values" for the flowrates at P1S2 and P2S1 and flowrate, fluid properties and composition at the Export point. The information can then be used as additional measurements (including uncertainties) when needed during the PSM-DVR runs, or as Reference measurement for the Export meter flowrate (similar to the LACT measurement).

The Reference case is also used as the benchmark "True Value" case to calculate the relative deviation of allocation quantities when influenced by the process and/or measurements errors; i.e. errors caused by flowrates, fluids properties or instrumentation. Combined and Exception runs are performed in PSM mode to evaluate the "Theoretical True Value" for each stream at the Export meter conditions. The Theoretical Quantity total matches well with the initial Export meter reading (less than 0.05% difference).

As with the Reference case generated in PSM mode, similar results are obtained in DVR mode with negligible penalties confirming the consistent behavior of the software package when run in either PSM or DVR modes.

4.3 Simulated Production Scenarios

Case 1: Actual Case - Moderate Imbalance

This case is identical to the Reference case except that the inlet separators' measurements were slightly increased to impart a positive 3.37% imbalance between the PSM-PROP Theoretical Quantity total and the Export measurement. Such imbalance is neutralized by prorating it to each of the inlet streams' Theoretical Quantity.

The model is then run in PSM-DVR mode where measurements are reconciled at their actual conditions. The reconciled values for each inlet separator are subsequently used in PSM mode to determine the DVR Theoretical Quantity at the Export meter. Because the system has been balanced prior to performing the Combined and Exception runs such run results in approximately the same value as the initial Export meter reading (less than 0.05% difference in most cases).

The DVR run is shown in Figure 4. The altered inlet streams are flagged according to the penalty values of Table 2. This is a key feature of the DVR processing as it allows the inspection of input data before considering the reconciled data for allocation. In this case three of the four inlet streams were identified as candidates for in depth investigation (flagged blue). Depending on the magnitude of measurement error and the number of variables (moderate in this case) the severity of corresponding penalties can change from one variable to another. In this software package, the streams with individual penalty higher than 1 are coded blue changing to red when it gets above 4 (1.96^2) indicating that the reconciled value is outside the 95% confidence level range defined for this measurement. Note that the reconciled value for each of the selected tags shows to the right of the measured value in the PFD figures.

Table 2 summarizes the allocated values and their relative deviation from the True Values. The Theoretical Quantity totals and imbalances are also shown for the PSM-PROP and PSM-DVR runs. Moreover, the DVR run provides information about the uncertainty of the reconciled (allocated) values along with the penalties. They are shown to the right of the reconciled values.

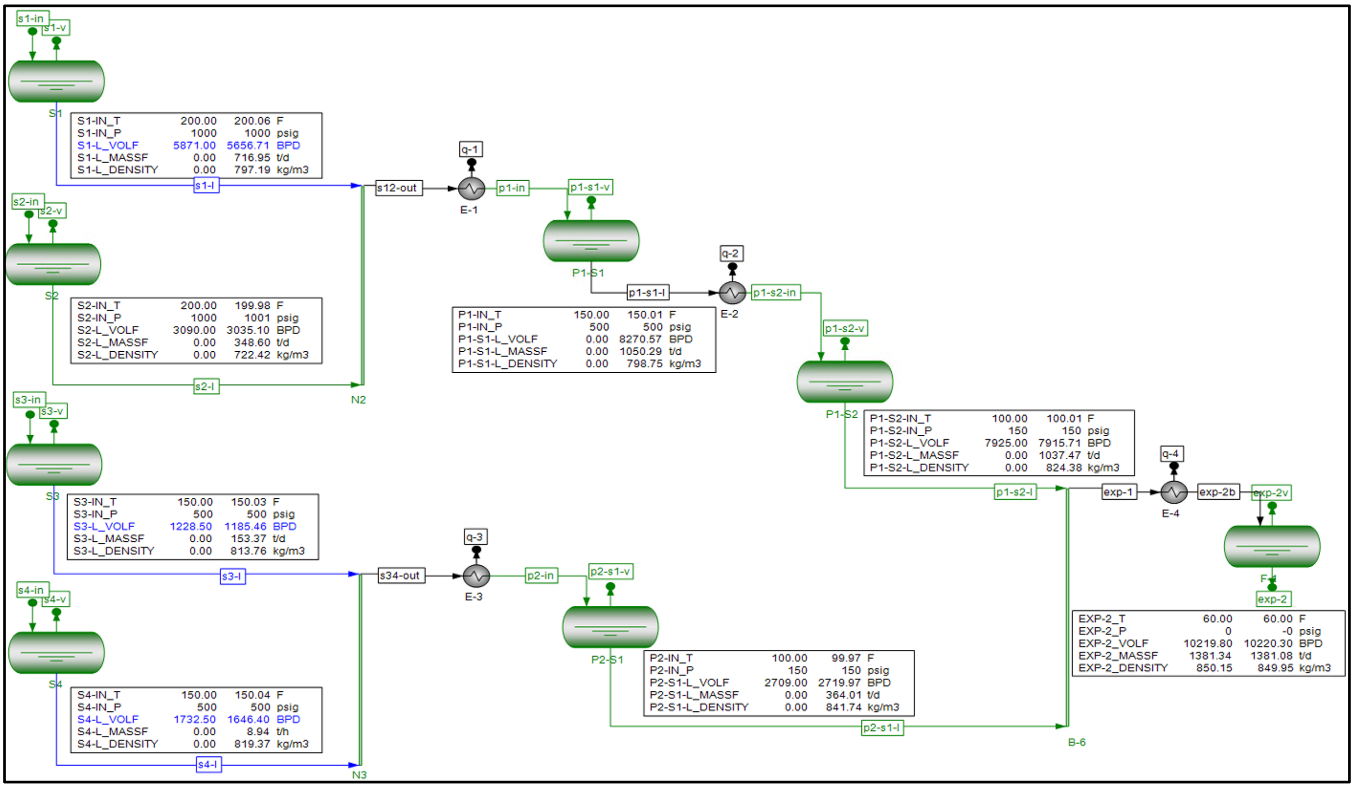
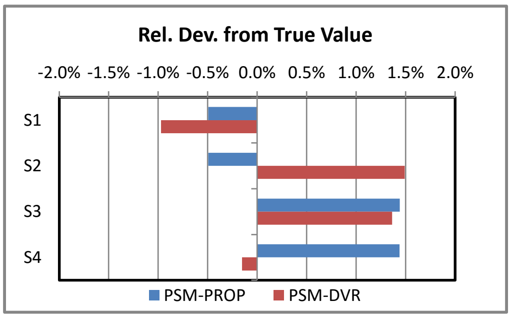


Figure 4 - DVR Run of Actual Case with Moderate Imbalance and Penalties

Table 2 - Case 1 Result: Moderate Imbalance

Case 1: Actual Case - Moderate Imbalance					
PSM-PROP		PSM-DVR			
STBD	%	STBD	%	Unc	Penalty
365.3	3.57%	7.6	0.07%		
10,585.1		10,227.4			
5,088.6	-0.49%	5064.2	-0.97%	2.0%	3.20
2,486.0	-0.49%	2535.6	1.49%	3.7%	0.76
1,092.0	1.44%	1091.2	1.36%	5.3%	1.31
1,553.2	1.44%	1528.8	-0.15%	4.1%	2.64



It can be seen from the graph of Table 2 that Proportional Allocation is done without consideration for the measurements' precision; the higher accuracy S1 and S2 measurements are allocated production volumes below the True Values to cover the gains of the less precise streams S3, and S4. This can somehow be justified by the fact that S1 and S2 streams were responsible for most of the positive imbalance in absolute terms.

The DVR reconciliation is driven and affected by the measurement uncertainty (Uncertainty Based Allocation - UBA) as was demonstrated in the simpler case of [1]. It is harder to interpret the results for each stream in this more complex case due to the number of variables including phase behavior and measurements uncertainties. However the measurements were reconciled to less than 2% deviation from the True Values as was the case with Proportional Allocation too. The added information about the uncertainties of the allocated quantities is a plus that is missing from the PSM-PROP run.

Case 2: Actual Case with Export stream fluid sample composition measurement

Before proceeding to analyzing other cases, it was decided to study the impact of integrating the fluid sample information obtained at the Export meter sampling station (equivalent to LACT station). This exercise is applicable to the PSM-DVR mode since such information cannot be used directly in the conventional PSM-PROP mode.

In the previous case, no sample information was entered for the stream EXP-2. The fluid composition was calculated by the PSM as unmeasured variables using the measurement of the inlet streams' compositions. It was possible to perform these calculations because there was sufficient information redundancy (7) in the system to perform the calculations - i.e. number of equations exceeded the number of unmeasured variables as shown in Table 3. In Case 1 the calculation of EXP-2 stream composition added more unmeasured variable at the expense of reducing the system redundancy. The decrease in system redundancy reduced the accuracy and precision of the reconciled variable as will be shown later.

By including the 12 components composition obtained from lab analysis as measured variables, the number of equations and measurements increased by 12 raising the system redundancy from 7 to 19. This added redundancy makes the system more "over-specified" leading to improved reconciled values of the inlet streams in addition to improved precision as shown in Table 4.

Table 3 - Number of Measurements and Redundancies

	Case 1 With Unmeasured Fluid Composition	**Case 2 With Measured Fluid Composition**
Number of equations	306	**318**
Unmeasured variables	299	299
Measured variables	72	**84**
Number of redundancies	7	**19**

It can be noted from Table 4 that the reconciled results of S1 and S2 have improved compared to Case 1 along with improved uncertainty. In this particular case it was assumed that the precision of the sample components are in the range of 2% (i.e. higher quality sampling and analysis at the LACT sampling station) compared to the 5% uncertainty assigned to inlet separators samples.

The added advantage of including the sample information in the calculations as new equations enables the reconciliation of phase components across the system; this will be shown to provide the benefit to detect potential problems with the fluids sampling and analysis inputs and can be used as an important KPI in accepting or rejecting the samples according to industry standards [12].

Figure 5 shows that the S2 stream penalty was flagged in addition to the other streams; the penalty increase in this case is a direct result of the reconciled value improvement as it moves away from the biased measurement result and closer to the True Value. Before interpreting the penalty changes of a given measurement it is important to address and reduce other penalties to minimize their interference especially when the errors are relatively small.

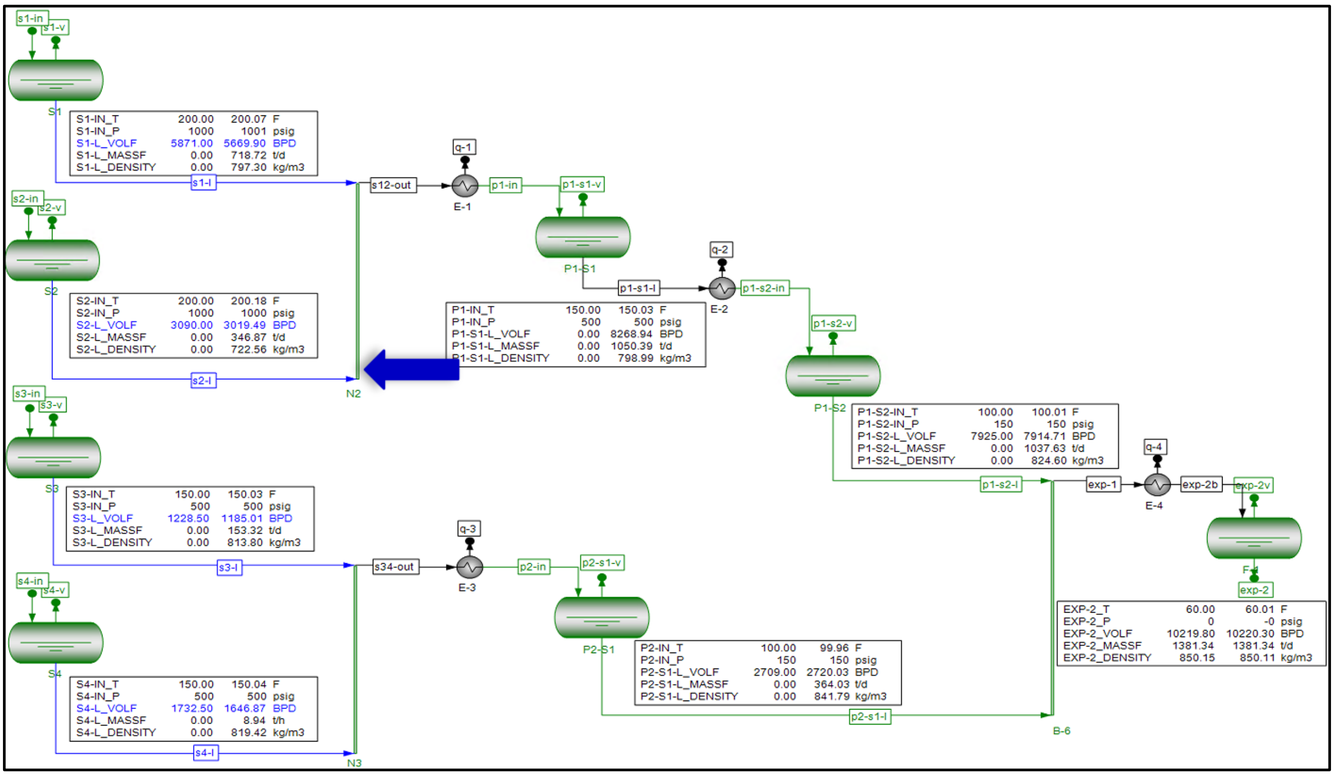
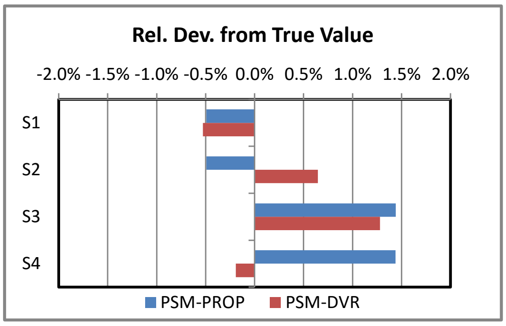


Figure 5 - DVR Run Moderate Imbalance and with Composition Measurements at Exp-2

Table 4 - Case 2 Result: Export Meter Sample Composition Added as Measurements

Case 2: Actual Case with Export fluid sample info.					
PSM-PROP		PSM-DVR			
STBD	%	STBD	%	Unc	Penalty
365.3	3.57%	6.3	0.06%		
10,585.1		10226.1			
5,088.6	-0.49%	5086.8	-0.53%	1.7%	2.82
2,486.0	-0.49%	2514.5	0.65%	2.9%	1.25
1,092.0	1.44%	1090.3	1.28%	5.2%	1.34
1,553.2	1.44%	1528.2	-0.19%	4.1%	2.61



Case 3: Increased S4 flowrate bias (Gross Error) applied to Case 2

A "Gross Error" is introduced to S4 flowrate measurement by increasing this measurement's positive bias from 5% to 9%, i.e. increasing the error beyond the measurement's 95% confidence level range of 6%. The system imbalance has also increased from 3.47% to 4.17%.

In this case S4 stream is flagged red (Figure 6) due to its penalty (5.35) exceeding the 4 boundary level (the boundary for the reconciled value deviation from the measurement's 95% confidence level range of uncertainty). Other inlet separators' measurements are also influenced but still within moderate penalty ranges.

Errors of such magnitude are usually noticed and should be corrected first before proceeding with the production allocation process (meter recalibration or fluid density correction are possible solutions). However, in the event that such gross error was overlooked and went undetected, it can be seen that the allocation results deteriorate significantly in the PSM-PROP mode as shown in Table 5.

The results of the PSM-DVR mode reflect the change in system reconciled profile due to the gross error but continued to be within the acceptable range of less than 2% deviation from the True Values.

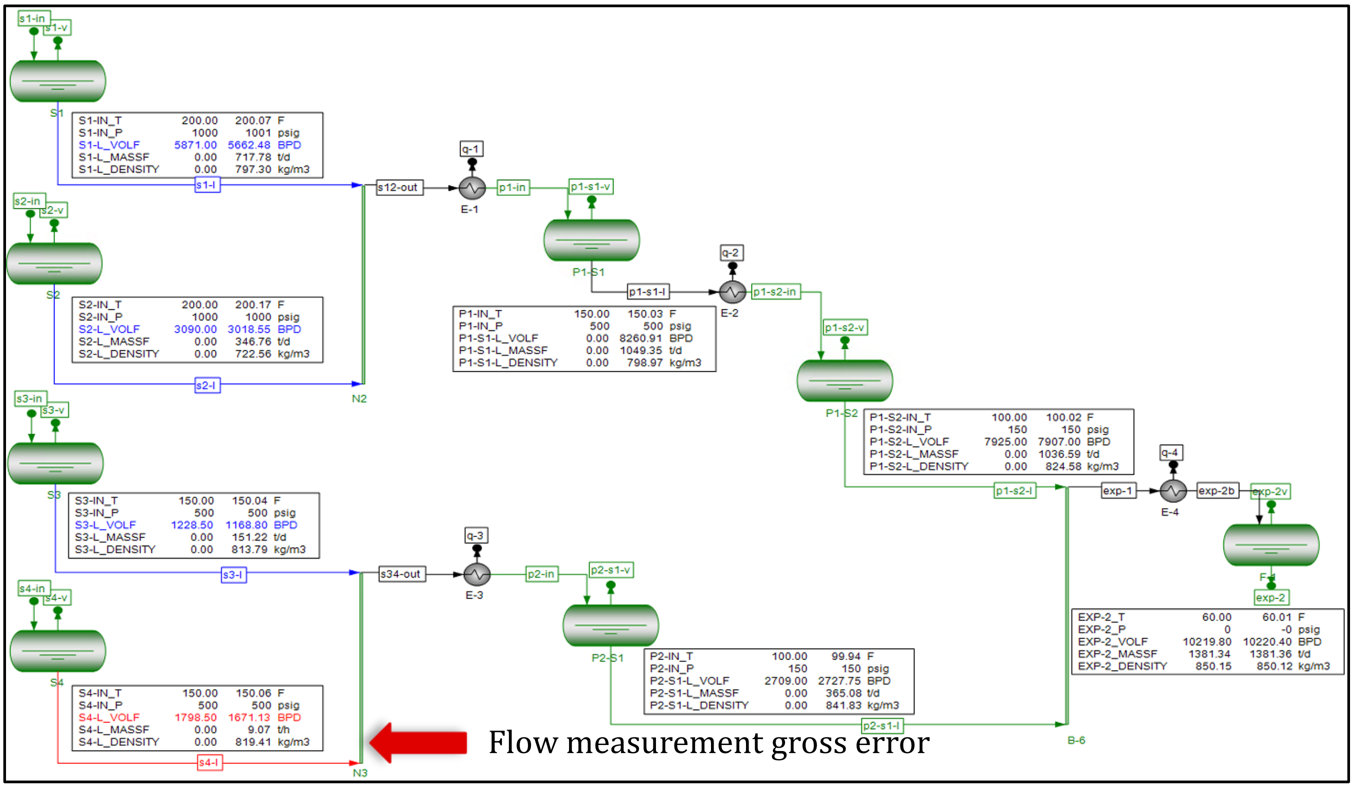
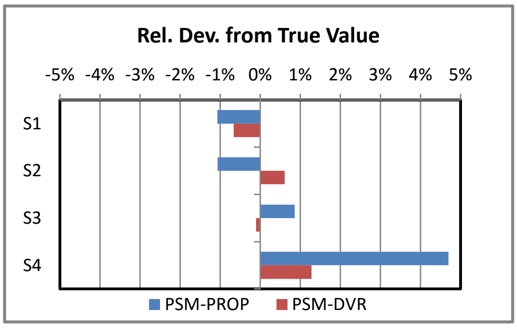


Figure 6 - DVR Run: Gross Error Identified at S4 Due to Flowmeter Measurement Bias

Table 5 - Case 3 Result: Gross Error Due to Increased Flowmeter bias at S4

Case 3: Actual with S4 Gross Error					
PSM-PROP		PSM-DVR			
STBD	%	STBD	%	Unc	Penalty
426.6	4.17%	6.6	0.06%		
10,646.4		10,226.4			
5,059.3	-1.07%	5080.1	-0.66%	1.7%	3.03
2,471.7	-1.07%	2513.7	0.61%	2.8%	1.28
1,085.7	0.86%	1075.3	-0.11%	5.3%	2.52
1,603.1	4.70%	1550.7	1.28%	4.1%	5.35



An obvious observation from the DVR results of Table 5 is that the damage caused by the gross error is mainly inflicted on the penalty parameter leaving the reconciled value almost unaffected. Furthermore, the measurement gets tagged for corrective action potentially leading to allocation results improvement. This contrasts with the PSM-PROP mode where the diagnostics features are lacking, and where much of the damage is inflicted directly on the allocated volume quantities.

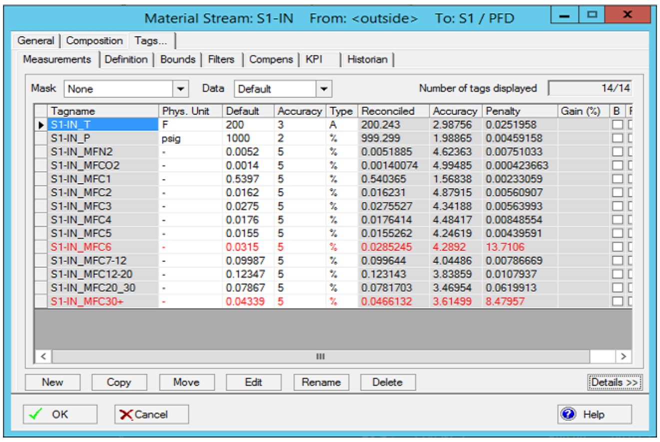
Case 4: S4 flowrate bias and S1 sample composition error applied to Case 3

Case 3 was further modified by introducing an error to S1 fluid sample. The error consisted of modifying the molar fraction by removing 0.7% from the molar fraction of C30+ component and adding it to the lighter component C6. In essence this led to the PSM erroneous treatment of S1 stream as having a lighter fluid, which is characterized by more shrinkage. The treatment was carried through the different separation stages to the Export meter. The net result is that the Theoretical Quantity total was reduced by approximately 12 STBD leading to an apparent lower imbalance compared to the previous case. This was the only observation made from the PSM-PROP run.

Conversely, the PSM-DVR run based on Figure 8, flagged three other streams red in addition to S4 indicating penalties in excess of 4. The three other streams are:

S1-in: the feed stream of inlet separator S1 with erroneous sample
S2-in: the feed stream of inlet separator S2
Exp-2: the Export meter stream

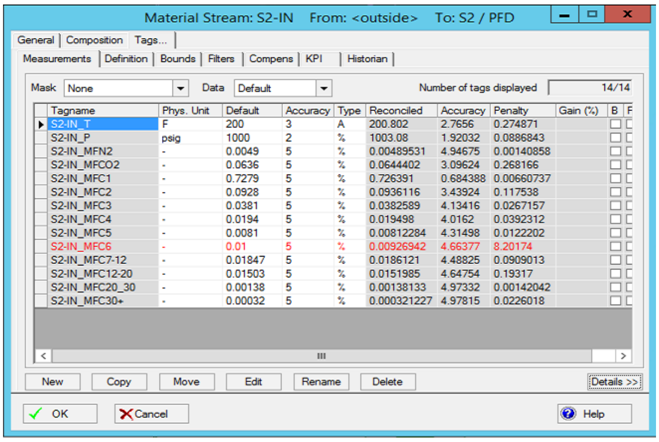
By examining the tags windows of the above streams (Figure 7) it can be concluded by triangulation that the most likely cause for increased penalties at S1-in, S2-in and Exp-2 are erroneous molar fraction inputs at S1. Of course this assumes that the composition input in Exp-2 stream as discussed in Case 2 above, is accurate and of high quality.



Material Stream: S1-IN From: <outside> To: S1 / PFD

Mask: None | Data: Default | Number of tags displayed: 14/14

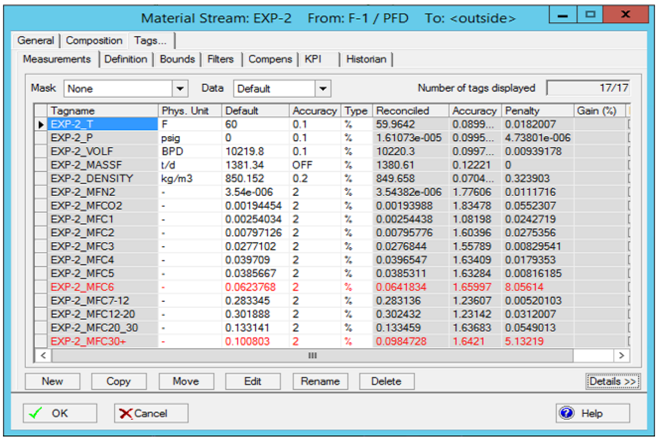
Tagname	Phys. Unit	Default	Accuracy	Type	Reconciled	Accuracy	Penalty
S1-IN_T	F	200	3	A	200.243	2.98756	0.0251958
S1-IN_P	psig	1000	2	%	999.299	1.98865	0.00459158
S1-IN_MFN2	-	0.0052	5	%	0.0051885	4.62363	0.00751033
S1-IN_MFCO2	-	0.0014	5	%	0.00140074	4.99485	0.000423663
S1-IN_MFC1	-	0.5397	5	%	0.540365	1.56838	0.00233059
S1-IN_MFC2	-	0.0162	5	%	0.016231	4.87915	0.00560907
S1-IN_MFC3	-	0.0275	5	%	0.0275527	4.34188	0.00563993
S1-IN_MFC4	-	0.0176	5	%	0.0176414	4.48417	0.00848554
S1-IN_MFC5	-	0.0155	5	%	0.0155262	4.24619	0.00439591
S1-IN_MFC6	-	0.0315	5	%	0.0285245	4.2892	13.7106
S1-IN_MFC7-12	-	0.09987	5	%	0.099644	4.04486	0.00786669
S1-IN_MFC12-20	-	0.12347	5	%	0.123143	3.83859	0.0107937
S1-IN_MFC20_30	-	0.07867	5	%	0.0781703	3.46954	0.0619913
S1-IN_MFC30+	-	0.04339	5	%	0.0466132	3.61499	8.47957



Material Stream: S2-IN From: <outside> To: S2 / PFD

Mask: None | Data: Default | Number of tags displayed: 14/14

Tagname	Phys. Unit	Default	Accuracy	Type	Reconciled	Accuracy	Penalty
S2-IN_T	F	200	3	A	200.802	2.7656	0.274871
S2-IN_P	psig	1000	2	%	1003.08	1.92032	0.0886843
S2-IN_MFN2	-	0.0049	5	%	0.00489531	4.94675	0.00140858
S2-IN_MFCO2	-	0.0636	5	%	0.0644402	3.09624	0.268166
S2-IN_MFC1	-	0.7279	5	%	0.726391	0.684388	0.00660737
S2-IN_MFC2	-	0.0928	5	%	0.0936116	3.43924	0.117538
S2-IN_MFC3	-	0.0381	5	%	0.0382589	4.13416	0.0267157
S2-IN_MFC4	-	0.0194	5	%	0.019498	4.0162	0.0392312
S2-IN_MFC5	-	0.0081	5	%	0.00812284	4.31498	0.0122202
S2-IN_MFC6	-	0.01	5	%	0.00926942	4.66377	8.20174
S2-IN_MFC7-12	-	0.01847	5	%	0.0186121	4.48825	0.0909013
S2-IN_MFC12-20	-	0.01503	5	%	0.0151985	4.64754	0.19317
S2-IN_MFC20_30	-	0.00138	5	%	0.00138133	4.97332	0.00142042
S2-IN_MFC30+	-	0.00032	5	%	0.000321227	4.97815	0.0226018



Material Stream: EXP-2 From: F-1 / PFD To: <outside>

Mask: None | Data: Default | Number of tags displayed: 17/17

Tagname	Phys. Unit	Default	Accuracy	Type	Reconciled	Accuracy	Penalty
EXP-2_T	F	60	0.1	%	59.9642	0.0899...	0.0182007
EXP-2_P	psig	0	0.1	%	1.61073e-005	0.0995...	4.73801e-006
EXP-2_VOLF	BPD	10219.8	0.1	%	10220.3	0.0997...	0.00939178
EXP-2_MASSF	t/d	1381.34	OFF	%	1380.61	0.12221	0
EXP-2_DENSITY	kg/m3	850.152	0.2	%	849.658	0.0704...	0.323903
EXP-2_MFN2	-	3.54e-006	2	%	3.54382e-006	1.77606	0.0111716
EXP-2_MFCO2	-	0.00194454	2	%	0.00193988	1.83478	0.0552307
EXP-2_MFC1	-	0.00254034	2	%	0.00254438	1.08198	0.0242719
EXP-2_MFC2	-	0.00797126	2	%	0.00795776	1.60396	0.0275356
EXP-2_MFC3	-	0.0277102	2	%	0.0276844	1.55789	0.00829541
EXP-2_MFC4	-	0.039709	2	%	0.0396547	1.63409	0.0179353
EXP-2_MFC5	-	0.0385667	2	%	0.0385311	1.63284	0.00816185
EXP-2_MFC6	-	0.0623768	2	%	0.0641834	1.65997	8.05614
EXP-2_MFC7-12	-	0.283345	2	%	0.283136	1.23607	0.00520103
EXP-2_MFC12-20	-	0.301888	2	%	0.302432	1.23142	0.0312007
EXP-2_MFC20_30	-	0.133141	2	%	0.133459	1.63683	0.0549013
EXP-2_MFC30+	-	0.100803	2	%	0.0984728	1.6421	5.13219

Figure 7 - Tags Windows of S1-in, S2-in and Expo-2 to Locate Source of Sample Error

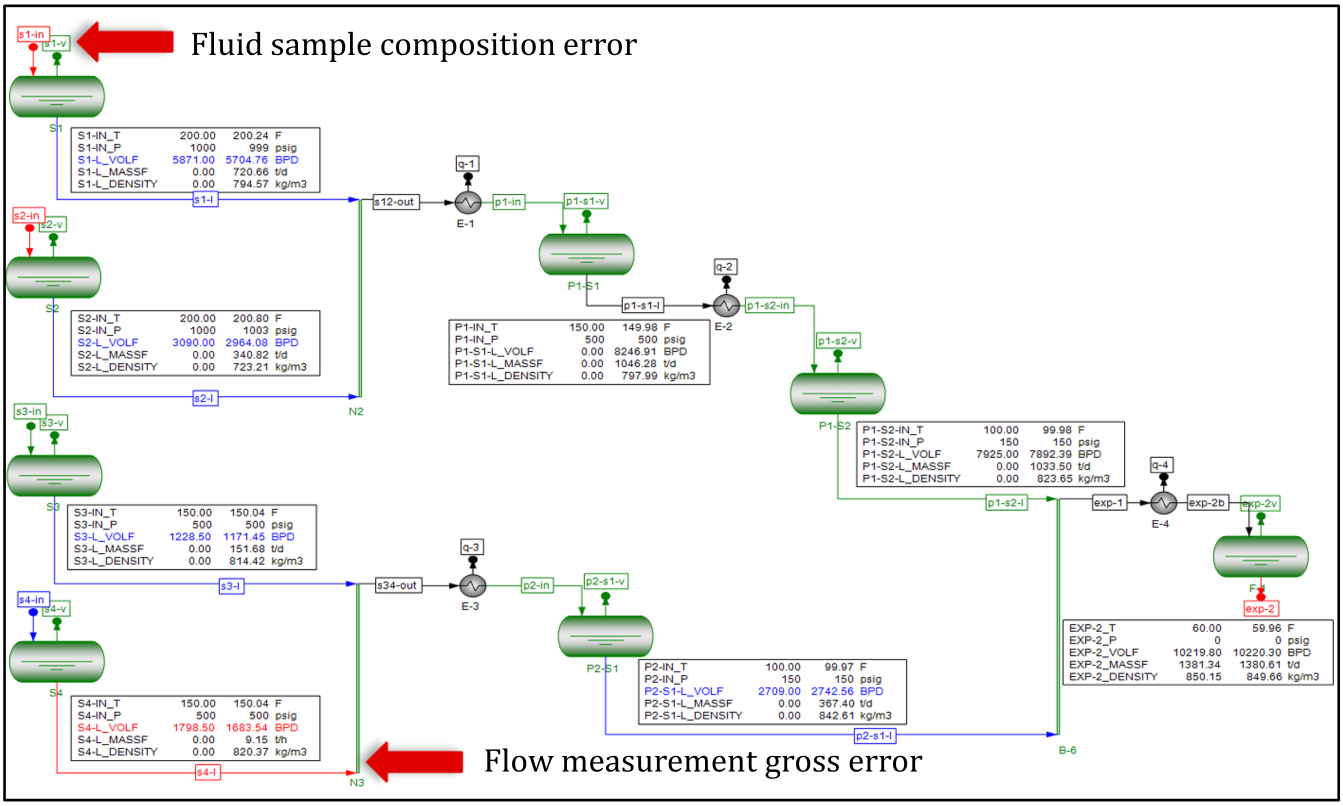
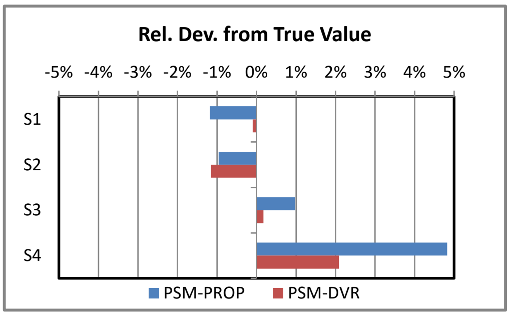


Figure 8 - DVR Run of Case 4 with S4 Flowmeter Bias and S1 Sample Error with Expo-2 Comp.

Table 6 - Case 4 Result: S4 Flowmeter Bias and S1 Sample Error with Expo-2 Composition

Case 4: S4 flow bias, S1 sample error, Exp. compo. & den.					
PSM-PROP		PSM-DVR			
STBD	%	STBD	%	Unc	Penalty
414.2	4.05%	1.1	0.01%		
10,634.0		10,220.9			
5,053.5	-1.18%	5108.9	-0.10%	1.7%	1.93
2,474.3	-0.96%	2469.5	-1.15%	2.9%	3.99
1,087.0	0.97%	1078.4	0.17%	5.3%	2.30
1,605.0	4.82%	1563.1	2.08%	4.1%	4.36



As expected, the results of the PSM-PROP run changed slightly because of the small reduction in the apparent imbalance assessed at the Export meter conditions. On the other hand, more adjustments are observed in the PSM-DVR results due to the integral use of the erroneous sample data in the reconciliation calculations. However, the results were still confined to about 2% deviation from the True Values.

It should be mentioned that such error detection was made possible by using the sample compositional analysis at the Export meter sampling station as input measurements. This in turn enabled the DVR reconciliation process to balance the streams' measured compositions rather than using computed or unmeasured compositions.

In the case of the PSM-PROP run, all compositions are forward-computed. Without a quality check procedure to compare the computed results with the actual composition at Exp-2 the erroneous sample data would not be identified.

Case 4a: Same as Case 4 but with liquid density measurement at Export meter

The case builds on Case 4 by maintaining the sample error at S1 but replacing the 12 liquid components measurements at the Export meter with one liquid density measurement. This may be the case if sample analysis are not performed and only certain properties such oil API° is available.

Again the results of the PSM-PROP run are not expected to change because the information at the Export meter is not included in the model's forward simulation. At best a comparison between the measured and calculated density values at the Export meter may reveal a discrepancy that could prompt actions to trace back the source of discrepancy and improve results.

The results of the PSM-DVR run are expected to be similar to Case 4 because in both cases the fluid density measurement was used to anchor the liquid properties at the Export meter. However it can be shown that the uncertainty of the reconciled flowrates increases slightly due to the reduction of system redundancy caused by the removal of composition measurements. Additionally, the absence of composition information limited the system's error detection capability by only indicating an increase of liquid density penalty at the Export meter (Figure 9) without making reference to the sample error at the inlet separator S1.

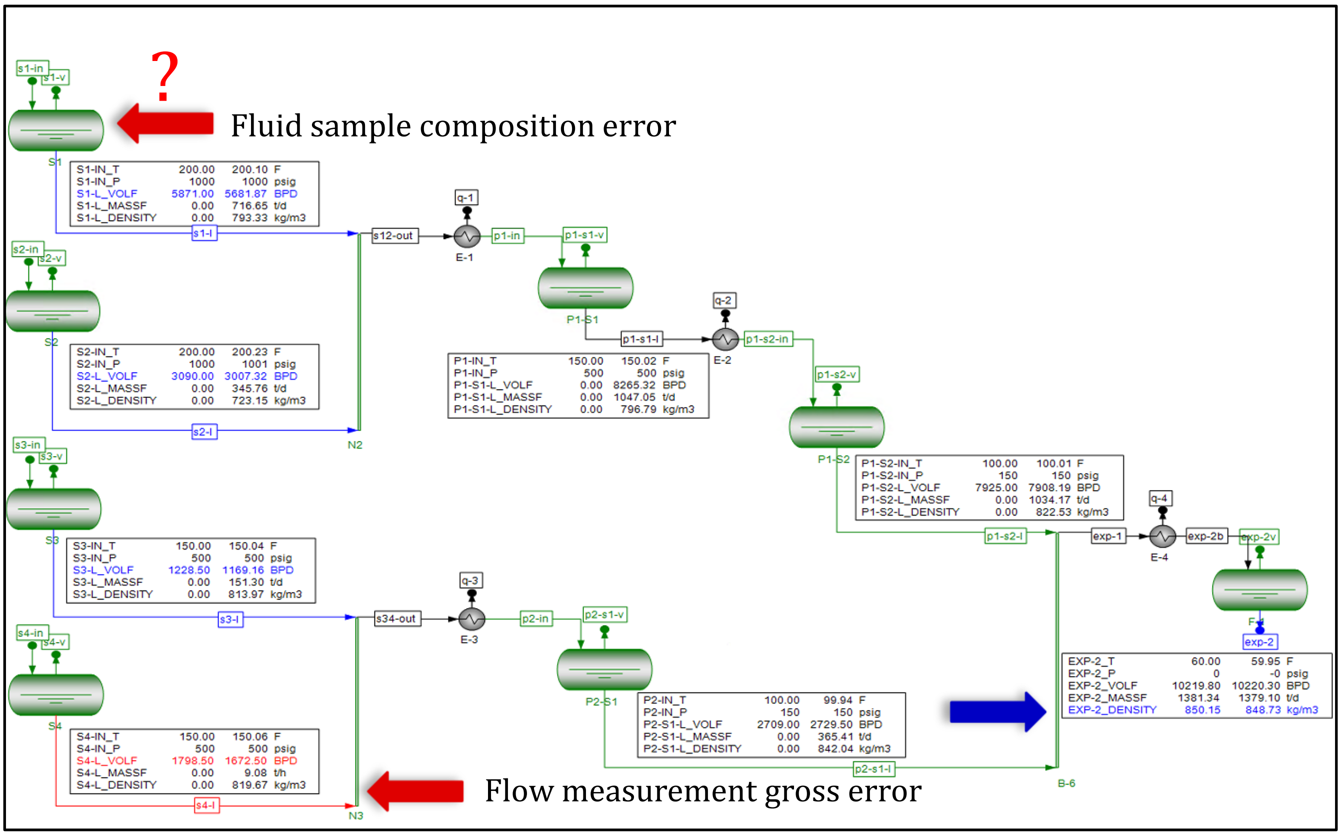


Figure 9 - DVR Run of Case 4a with S4 Flowmeter Bias and S1 Sample Error with Expo-2 Liquid Density and No Sample Composition

Case 5: Analysis after flowmeter calibration and sample error elimination

With the ability to detect potential biases and errors in the flow measurement and/or fluid samples, the erroneous data can first be corrected before proceeding to the allocation phase. This was done in this case by using the information gained from the PSM-DVR surveillance results to eliminate the gross error in S4, remove the molar fraction errors in the fluid sample of S1, and recalibrate all inlet flowmeters. Compared to Case 1, the flowmeters performance has been improved according to Table 7, while their uncertainty specification (precision) remained unchanged (4%-6%):

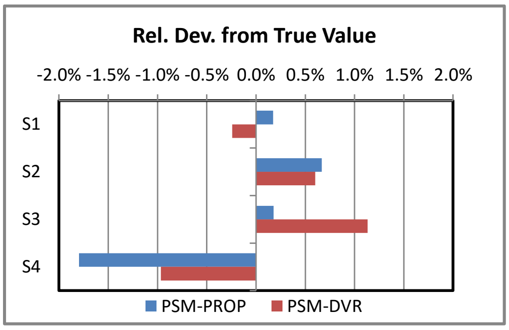
Table 7 - Assumed Flowmeters Bias before and after calibration - % of True Values

Inlet Separator	Case 2 (before calibration)	Case 5 (after calibration)
S1	3%	1.5%
S2	3%	2.0%
S3	5%	1.5%
S4	5%	-0.5%
Imbalance	3.57%	1.39%

Following the corrective action the improved measurements were used in both allocation schemes, PSM-PROP and PSM-DVR as shown in Table 8.

Table 8 - Case 5 Result: After Flowmeters Calibration and Sample error Elimination

Case 5: After meters calibration and sample error corr.					
PSM-PROP		PSM-DVR			
STBD	%	STBD	%	Unc	Penalty
141.8	1.39%	6.0	0.06%		
10,361.6		10,225.8			
5,122.8	0.17%	5101.4	-0.24%	1.7%	0.71
2,515.0	0.67%	2513.3	0.60%	2.8%	0.45
1,078.4	0.18%	1088.7	1.13%	5.0%	0.01
1,503.6	-1.80%	1516.4	-0.97%	4.0%	0.02



Noticeable improvements are seen in the allocation results, which translate to reduced average relative deviation from the True Values. Most individual streams deviations are contained within 1%. The larger negative excursion of S4 allocated quantity in the PSM-PROP mode is due to the "irregular" measurements bias contributions with negative bias assumed for S4.

The PSM-DVR run penalties are also reduced to below 1 indicating closer match between the reconciled measurements values ("True Values surrogate") and the actual flowrate measurements. Overall system consistency is achieved between the measurements, the input parameters and the system's physical model.

Regardless of the allocation formulation scheme adopted by the user, the above diagnostics and corrective steps are essential to achieve optimal and equitable allocation results.

Case 6: Case of loss of inlet flowmeter

The case examines the impact of losing physical sensors due to equipment failure or unavailability. This may apply to any device in the system; however in the case of production allocation, the loss of an inlet flowmeter can be critical and highly disruptive.

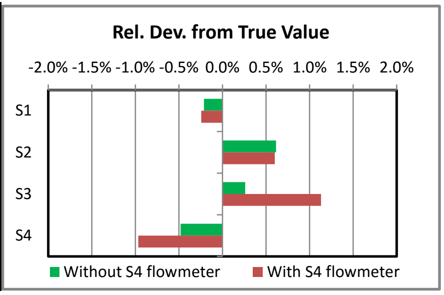
The simultaneous inclusion of all system available information (flowmeters, fluid samples, process conditions, physical constraints) in the PSM-DVR model provides efficient and quantifiable way to recover from this situation - at least until the faulty meter is replaced. Provided sufficient data redundancy is present, the removal of a device from the system is automatically substituted for by its measurement reconciled value and associated uncertainty.

While other modeling approaches can also be used to perform this recovery task, the limited information (inlet flowrates and samples analysis and Export meter flowrate in the case of PSM-PROP methodology) may be insufficient to arrive at a unique estimate for the missing inlet flowrate. Iterative "by-difference" volumetric and mass based calculations will be required to obtain an estimate. However the results will be unquantifiable in the presence of even small errors in the other streams and/or other phases. Ultimately, all the other streams errors/biases, which cause production imbalance, will systematically accumulate in the estimated/unmeasured flowrate of the stream that is missing the inlet flowmeter.

The corrective action based on the PSM-PROP methodology was not attempted in this work, instead, comparative analysis was done using Case 5 configuration to recover S3 flowmeter (Table 9).

Table 9 - Case 6 Result: Case of Loss of Flowmeter at S3

Case 6: Comparison of Case 5 results with and without S3 flowmeter							
DVR **without S3** flow measu.				DVR **with S3** flow measu. (Case 5)			
STBD	%	Unc	Penalty	STBD	%	Unc	Penalty
6.0	0.06%			6.0	0.06%		
10,225.8				10,225.8			
5,103.0	-0.21%	1.7%	0.69	5101.4	-0.24%	1.7%	0.71
2,513.7	0.62%	2.8%	0.44	2513.3	0.60%	2.8%	0.45
1,079.3	0.26%	**9.3%**	0.00	1088.7	1.13%	**5.0%**	0.01
1,523.8	-0.48%	5.9%	0.00	1516.4	-0.97%	4.0%	0.02



Train2 is the most affected by the new estimate. The surprising result in this case is the reduced deviation from the True Value compare to the case with meter availability; with meter removal, the stream's bias (-0.5%) was also removed and with sufficient system redundancy the reconciliation was also improved. However the improvement is also tagged by increased uncertainty from 5% to 9.3%. The other streams estimates and uncertainties were almost unchanged especially S1 and S2 of Train1. This led to similar average deviation for both cases and confirms the fact that the PSM-DVR approach is not subjected to the "by difference" shortfalls.

Losing a flowmeter (or other devices) is a situation that production operations will likely face at one point in the life of a project. This can have serious consequences if such meter is irreplaceable in the short term. This situation is quite applicable to subsea MPFMs where substitute flowrate estimates by-difference or from Virtual Flowmeters (VFM) is often used. Adopting the DVR approach will add another level of rigor as shown in the above example; in this situation the simultaneous use of DVR in the well model (VFM) and the system model (PSM-DVR) will further improve the results at the well where the meter became unavailable, and at the system level for allocation and reservoir management.

5 DVR PRACTICAL CONSIDERATIONS AND SUMMARY

5.1 Surveillance versus Allocation; What is Needed?

The use of a PSM and/or DVR software package depends on the intended application. For surveillance application the integration of PSM and DVR capabilities in single software is not required. This would be the case if a PSM software package is already employed to perform the PSM-PROP modeling and allocation calculations. The addition of a separate DVR package will be for surveillance and diagnostics applications. In this case DVR devised corrective actions and improvements can be implemented before proceeding with the PSM-PROP runs.

If a DVR-based allocation (Uncertainty Based Allocation for complex systems) is required, an integrated PSM-DVR software package will be required to perform the surveillance and allocation functions. As shown before, the initial PSM-DVR run is performed to check the system for erroneous data, and if none are found, the measurement reconciled values from this run are fed to the PSM standalone mode of the same package to perform the Combined and Exception runs. The allocated volume quantities are obtained directly by differencing each of the Exception runs from the Combined run. No further proration is required because the system has already been balanced during the initial PSM-DVR run.

The need to use an integrated PSM-DVR package stems for the fact that commercial PSM packages use different internal models / EOS versions. Residual differences won't cancel out if distinct software packages are used to perform DVR then PSM runs for the allocation application.

5.2 Uncertainties of Allocated Quantities - Improvement with Redundancy

In a DVR run uncertainties are calculated for all system variables, measured and unmeasured variables. This feature is only available in the PSM-DVR mode and is an important addition to the qualification of allocated volume quantities. In other words, the allocated quantities are qualified by their uncertainties in addition to their absolute values. This qualification will aid in reducing the risks associated with the measurement/data quality, or lack thereof, that is used in allocation calculations. An example was shown in Case 6 above where the use of unmeasured flowrate in S3 due to flowmeter unavailability resulted in much higher uncertainty for this variable.

Moreover, the DVR approach provides the added advantage of improving the allocated quantities uncertainties with the inclusion of as many measurements as available in the production system/facility. It was shown that more measurements lead to more system redundancies which in turn lead to improving the uncertainty of the reconciled values. In production environment, measurements sources are not limited to physical sensors, meters, or devices. They can be fluid composition form lab analysis and other fluids properties as well as any other production KPI's such as Gas Oil Ration (GOR) if deemed accurate and usable as another piece of information [9].

Figure 10 summarizes uncertainty improvements in the above studied cases as more measurements were added to the PSM-DVR model. It was also noted that depending on the type of added measurements, the model diagnostics capabilities can change. This was observed in Cases 4 and 4a.

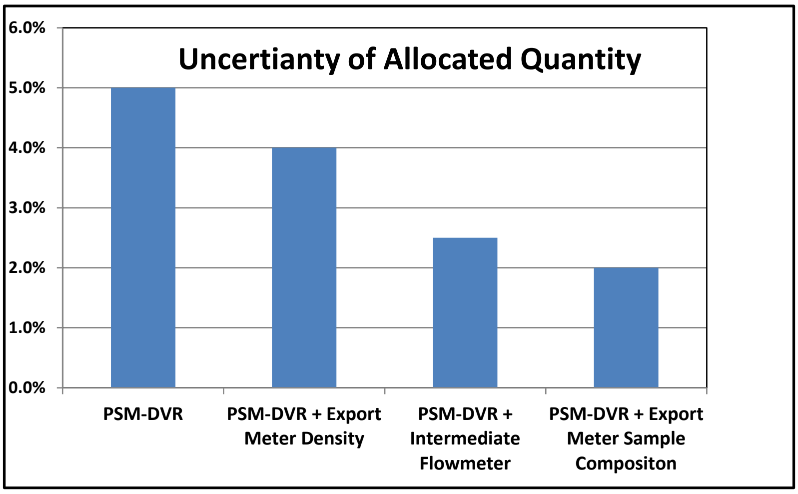


Figure 10 - DVR Run - Reduction of Allocated Quantities Due to Added Measurements

5.3 Penalties Trending for Surveillance

In the surveillance mode, DVR is best used by visualizing the trend of a measurement penalty. A schematic view of the penalties tracked in this study is shown in Figure 11.

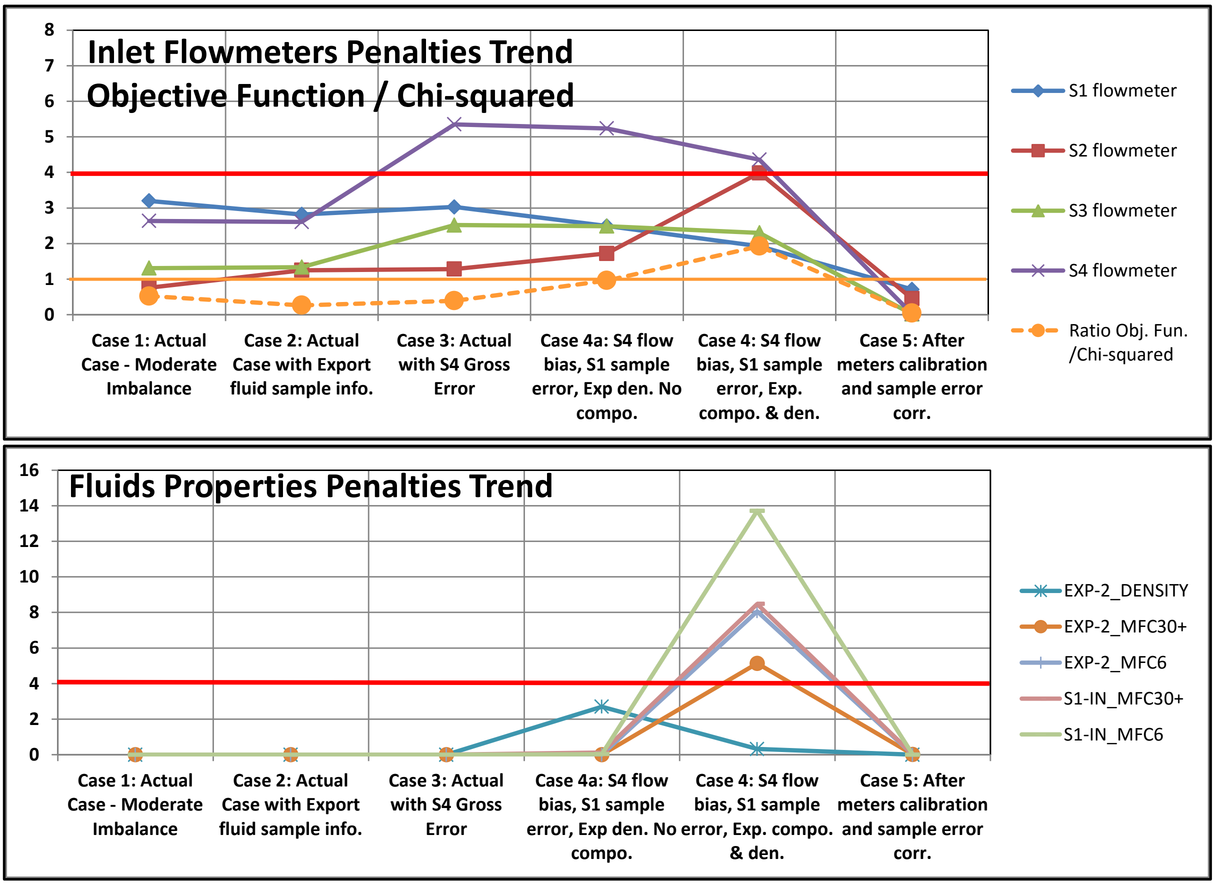


Figure 11 - Schematic Presentation of DVR Penalties in Surveillance Application

Only the affected measurements trends are shown for the inlet flowmeters and fluid samples at S1 separator and Export meter station. By correlating the trends from the two groups of measurements, the onset of different events can be detected and interpreted for their interaction with each other; the bias of S1 flowmeter is clear in Cases 3, 4a, and 4 while the anomaly on the Export meter density trend indicates potential fluids problems. It was not until the Export meter fluid composition was introduced as measurement that the source of fluids anomalies was attributed to S1 sample, and more particularly to the components C6 and C30+. Once all errors were removed and the meters calibrated to better accuracy, all trends returned closer to zero penalty in Case 5.

Another aggregate parameter, the Global Test, can also be monitored to assess the process overall health. This would be the first line of defense before looking things up in more details, tag by tag. The ratio of the Objective function over the Chi-square function is indicative of any anomalous trends, especially if it rises above 1 as shown in the upper graph of Figure 11. The more measurements / redundancies built in the process the more sensitive it is.

With the DVR approach, system surveillance and data trending to identify potential problem uses differential-data such as measurements penalties in addition to trending the measurements absolute values; this approach carries an important advantage because measurement values change with process changes, but differential-data trending is more sensitive to measurement anomalies. Isolating potential issues is made easier and better quantified by using penalties trends.

Compared to conventional process monitoring approaches, DVR fills an important void in any allocation process by providing a dynamic reference as close as possible to system's "True Values". The reference consists of the reconciliated measurement surface (or topography) used by the penalties calculations to generate the differential-data; As long as the penalties are contained, the differential-data surface will remain low and gradually changing across the process. Any considerable rise in penalty values will translate in spikes easily detectable.

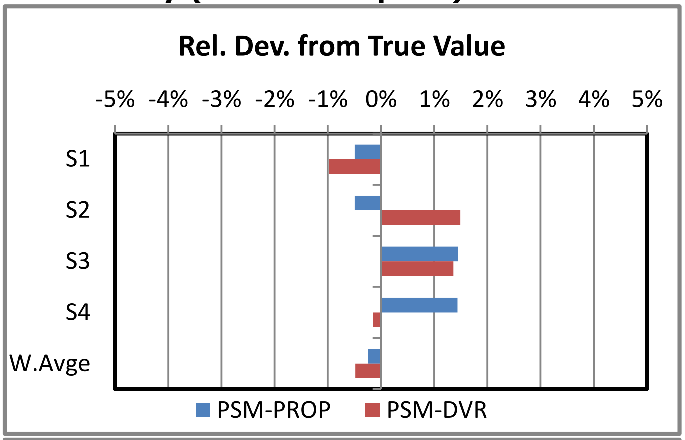
5.4 System Optimization and Analysis

Because of the simultaneous solving of all measurements equations in a DVR model, the impact of any single measurement on the sought solution can be quickly studied by making the runs with and without the measurement in question. Other sequential approaches may also be used but will lack the accuracy and the automated features of a DVR model. This feature was highlighted in Case 6 and is addressed in more details in [13].

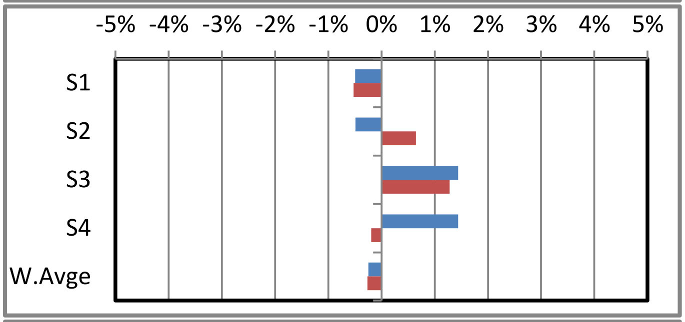
5.5 Cases Summary

To better visualize the relative effect of different changes made to the PSM-DVR model in this study, the relative deviation plots are shown together using the same scale. A summary and comments are provided for each case next to the plot.

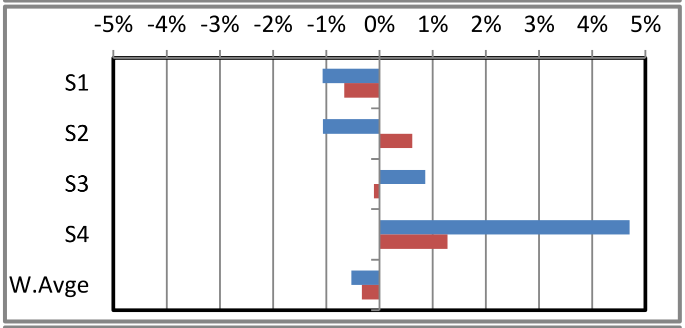
Summary (same scale plots)



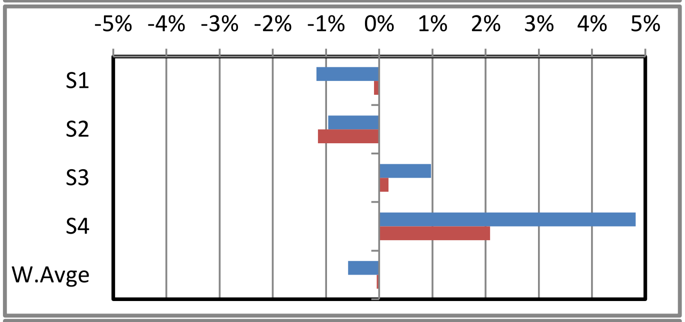
1)Actual Case
Imbalance 3.37%
Inlet flowrates:
S1 Ref flowrate plus 3% bias
S2 Ref flowrate plus 3% bias
S3 Ref flowrate plus 5% bias
S3 Ref flowrate plus 5% bias
Fluids: Same as Ref case
Comments: Allocated volumes are within 1.5% of Ref values.
Prop Allo: S1,S2 under allocated
S3,S4 over allocated
DVR results driven by evaluated measu. bias and precision, and process balances.



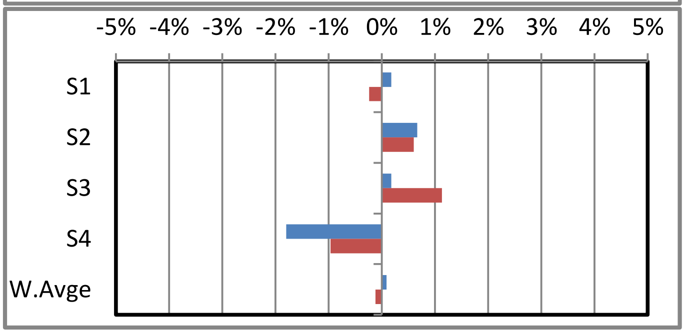
2)Actual Case with Export fluid composition
Imbalance 3.37%
Inlet flowrates: Same as case 1
Fluids: Exp Ref fluid composition used as measurements (12 added tags) in DVR reconciliation
Comments: Improved DVR reconciliation in S1, S2 with additional information. No change in Prop Allo; Added data not integrated and not used.



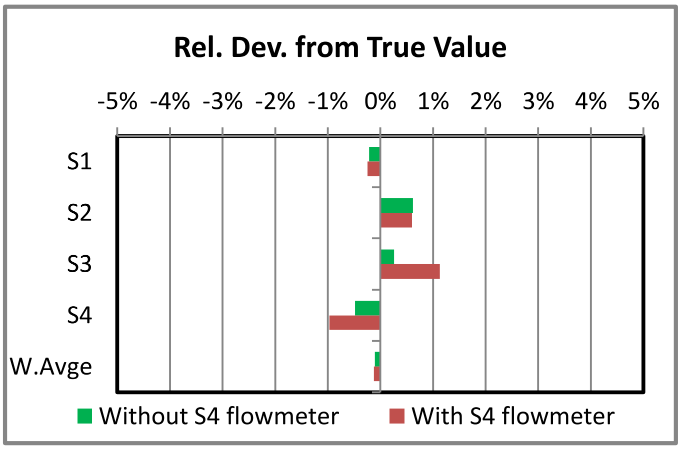
3)Actual Case and S4 increased bias
Imbalance 4.17%
Inlet flowrates: Same as case 1. Increased S4 4% - Total 9% bias
Fluids: Same as case 2
Comments: In Prop Allo, S4 is 4.8% over allocated due to significant imbalance in Train 2. Train 1 under-allocated by 1%.
DVR results moderately affected by S4 bias and remain below 1.3% deviation



4)Actual Case with S4 +bias and S1 sample composition error
Imbalance 4.05%
Inlet flowrates: Same as case 3. **Fluids:** Same as case 2 - S1 sample error 0.7% increase C6, decrease C30+
Comments: Only 16 BPD reduction in imbalance due S1 lighter apparent fluid (more shrinkage). Allocation adjustments with slight deviation increase from Ref case DVR within 2%.



5)After meters calibration, S4 bias and S1 sample error elimination
Imbalance 1.39%
Inlet flowrates: (residual bias after calib.)
S1 Ref flowrate +1.5% bias
S2 Ref flowrate +2.0% bias
S3 Ref flowrate +1.5% bias
S3 Ref flowrate -0.5% bias
Fluids: same as Ref case
Comments: Improvements guided by DVR penalty evaluation. Not available in Prop Allo but helps improve either method. Prop Allo impacted by measurement bias irregularity

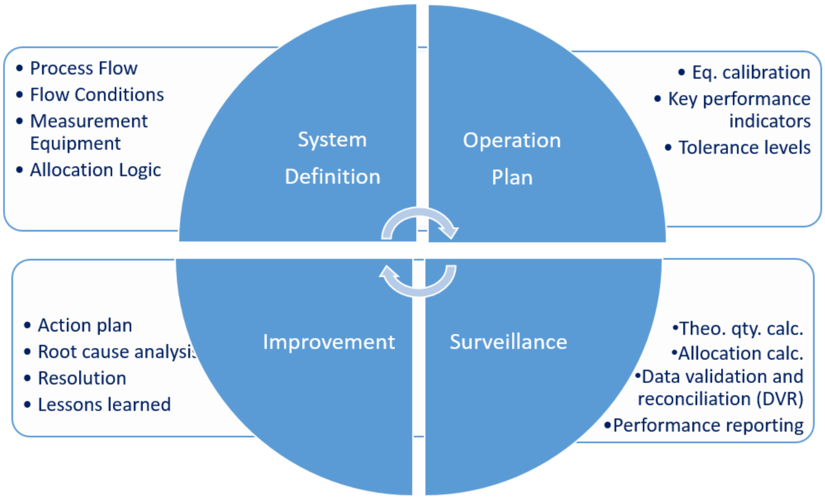


6) Loss of Inlet Flowmeter at S3 after error correction (Case 5).
Imbalance: 1.39%
Fluids: same as Ref case
Comments: This is identical to Case 5 but after the loss of flowmeter at S3. Graph shows the results with and without the meter. With enough redundancy in the system soft sensors can be created. In this case, S3 flowmeter is substitute by a soft flowmeter that can be used in the allocation process.

6 CONCLUSIONS - RECOMMENDATIONS

Production Allocation Measurement Management

Data validation and reconciliation (DVR) acts as an engine that drives the performance improvement and sustainability of the production allocation measurement system. DVR is the part of the surveillance program where data analysis adds value in identifying errors and performance shortfalls. However, while DVR is at the heart of production allocation measurement performance management, DVR needs to be combined with other parts of performance management in order provide complete the assurance cycle.



This figure illustrates the production allocation measurement assurance cycle. The upper activities define the production allocation measurement system and the operation plan used to maintain the systems performance. The lower activities use the system definition and operational activities as input surveillance and improvement activities. When the four activity sets, system definition, operational plan, surveillance, and improvement, are combined a complete production measurement system can be managed more effectively to assure performance.

1) System Definition

System definition is foundational to DVR efforts. It is essential that the DVR effort knows where the data being analyzed is coming from within the process flow.

The system definition activity defines the process flow, the associated measurement equipment and the allocation logic. The system definition is used to evaluate the capability of the equipment in terms of random uncertainty and bias tendencies considering the relative flow conditions. The system definition is especially helpful in providing non-operating parties and governmental agencies with a transparent view of the measurement and allocation parts of the system. It can also provide some insight into the performance expectation in terms of risk of measurement uncertainty and allocation inequity.

There are key documents that should be developed and maintained as part of the system definition. The primary document is called a "measurement" process flow diagram or MPFD. The MPFD describes bot the process flow and the relative allocation measurement systems. Another key document is the allocation logic diagram. This document might take multiple forms, but ultimately the objective of the document is to describe the allocation formulation relative the measurement data being created by the equipment and logged into the data historian. The diagram can also serve as a blueprint for the configuration of the allocation software and for subsequent audits of the allocation calculations.

2) Operational Plan

The key point of the operational plan relative to the DVR effort is the defining of the key performance indicators (KPI) and the out-of-tolerance levels. These two basic elements help support DVR in defining what data to analyze, and identifying when there is a likely errant measurement. Conversely the DVR activity can also lead to changing the operational plan in both a more or less aggressive manner. DVR can demonstrate where the frequency of validation and calibration activities should be increased. But, DVR can also show where instrument stability justifies decreasing the verification and calibration frequency. The goal of the operation plan is to optimize human activity versus the associated financial and HSSE risks.

3) Surveillance

For the most part surveillance is data validation and reconciliation. Because the other sections of this paper thoroughly discuss DVR, nothing more needs be said here. The end of the surveillance activities includes performance reporting. This rather simple step is a critical part of the process because it definitively ties the recognition of poor performance to the improvement activities that addresses it.

Often a step is inserted between surveillance and improvement activities. This step is best described as a justification and clarification step where a case to take action is presented with an estimation of activities (e.g. man-power, cost, schedule, etc.). This step is especially necessary in offshore and remote operations where extra technical staff and activities require a certain extra effort in logistics.

4) Improvement

The work exerted in defining the system, operational planning, and surveillance, comes to fruition in the improvement segment of the assurance cycle. The improvement activities take action on the outcomes of the surveillance activities. It also utilizes all the system definition and operational plan information together with the wealth of data collected and analyzed by the surveillance / DVR activities. By using all the data as a resource the improvement activities can utilize root cause analysis and continuous improvement techniques to resolve measurement system errors and performance shortfalls.

By resolving the various issues, a variety of positive outcomes are realized. First, most often the integrity in terms of accuracy and stability of the measurement results are improved. Where improvements are limited, an evaluation of the technical limitation of the equipment is addressed, which may result in a modification of the capability assessments. Learned lessons are captured, which can lead to codification of procedures and processes or amending existing technical practices and standards. The ultimate object of the improvement activities is improved performance and future avoidance of like incidents.

Through the study of simulated production scenarios the paper highlights ways to detect and deal with errant data in production allocation data sets. It also proposes and evaluates a practical procedure that turns DVR error-qualifiable production data into allocated quantities the same way traditional PSM systems are used in production allocation. The difference is that in the latter approach the data qualification for potential data bias or imprecision is not integrated in the allocation process leaving room for production misallocation risks.

7 ACKNOWLEDGEMENT

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