TERRALINK

WHITE PAPER

PRODUCTION MEASUREMENT OPTIMIZATION

2019

TABLE OF CONTENTS

1. UPSTREAM ORGANISATION'S CHALLENGES

Upstream organizations are under more and more pressure to improve keep performance measurements from internal and external stakeholders. Although the final number of Key Performance Indicators (KPI's) for an upstream organization may number in the hundreds. Most upstream strategies are aligned with some form of the 10 KPI's shown in Diagram #1. More recently there appears to be a stronger focus and interest in two specific KPI's: reduction of operating costs, capital expenditure efficiency.

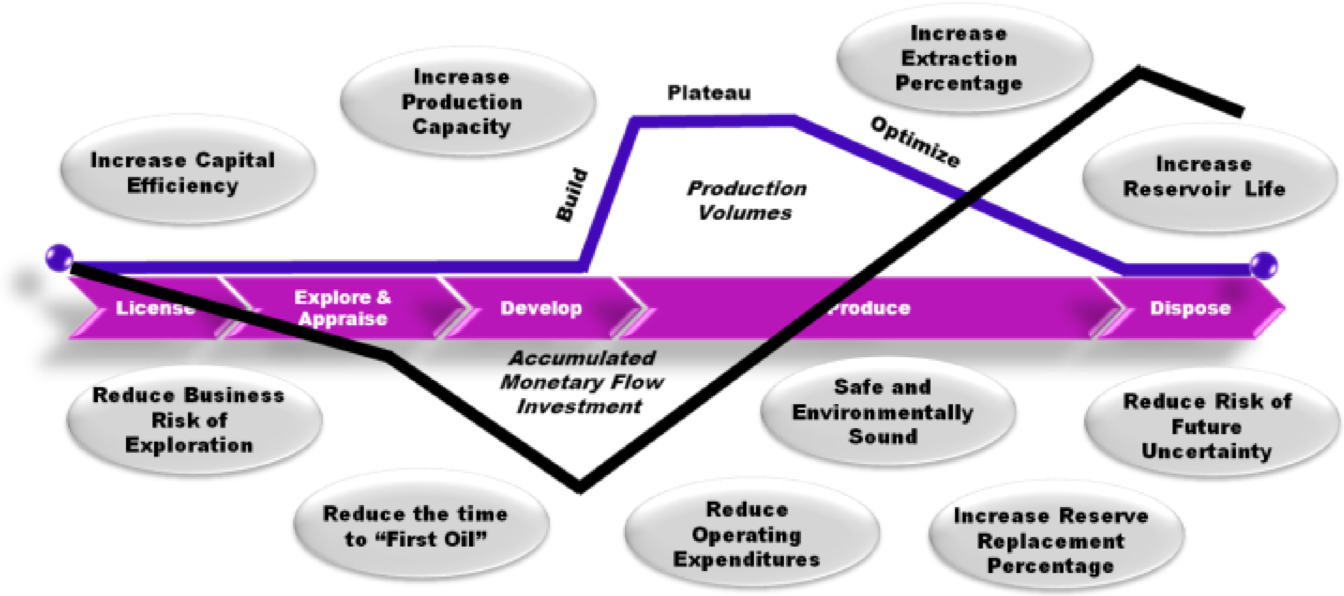

Diagram #1: High level Upstream performance measures

We understand that one of the best ways to manage the performance of your upstream assets is through the production and measurement and back allocation processes using the KPI Hydrocarbon Allocation Factor as a performance measure. The effectiveness of these processes can have either a direct or indirect affect on the majority of the measures presented in Diagram #1.

We would like to provide our thoughts regarding the optimization of the production measurement and allocation business processes using the Hydrocarbon Allocation Factor (KPI) by responding to commonly asked questions using our experience and our innovative and proprietary "Oilfield Lifecycle Management Solution" (OLMS) (Diagram #2) as background.

 www.terralink-global.com info@terralink-global.com

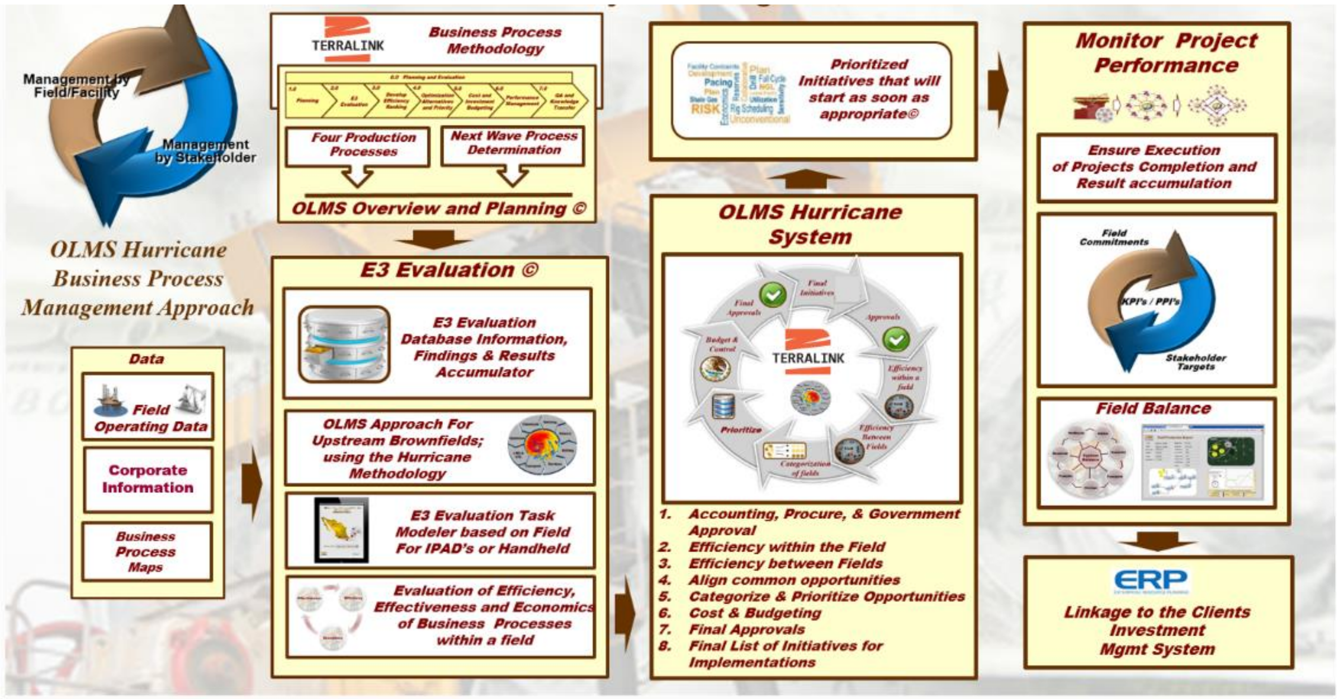

Diagram #2: Oilfield Lifecycle Management Solution

At this point it is important to establish baseline assumptions and facts to ensure we are all on the same page.

- An Oilfield is defined as the surface area overlying a geologic formation containing a hydrocarbon reservoir or reservoirs. The term usually includes not only the surface area, but also the reservoir, the wells, and the production equipment. The number of oil and gas oilfields in the world is believed to be about 40,000.
- A reservoir is a porous and permeable underground formation containing an individual and separate natural accumulation of producible hydrocarbons which is confined by impermeable rock or water barriers and is characterized by a natural pressure system.
- Each oilfield and associated reservoirs are independent and unique physical systems subject to Homeostasis. As a result, effort should be made to keep the oilfield in balance and management of the production measurement process is a key component of this balance (Diagram #3 Oilfield Balance)
- Due to homeostasis of the physical system, any changes made to the physical system or reservoir may have an effect upstream or downstream of the change. This issue must be always considered whether the change is a planned or unplanned change.
- The management of Greenfields or new development is very different from the operational management of Brownfields or fields that are in some level of decline. It's clear that new exploration, development and young producing field assets (greenfields) have the production volumes or reservoir potential to justify the acquisition and maintenance cost of these new technologies. It is a much cloudier issue surrounding the management and allocation of the limited financial and human capital for the maintenance and optimization of older fields (brownfields). Globally, 70% of the world's production comes from brown-fields operating for several decades with a current average daily well crude production of less than a half tonne.

Optimizing the Upstream Business Processes

- It's not practical to consider the optimization of all operational and related business processes within the upstream sector. There are several thousand processes, of which many are affected by the different combinations of attributes that make each oilfield and reservoir unique. The numbers of processes and the ranges of potential performance measures grow dramatically and as a result, it is possible that performance measurement directives from management can be misleading especially as the field or reservoir ages.
- There is a perception that if you optimize a business process, you will improve performance surrounding the process. It many cases this may be true. However, every operational business process has an almost limitless number of variances and constraints depending on the individual field therefore the management priorities of.

One of the key questions that must be addressed in the future of upstream optimization is the primary point of focus. More specifically do we focus on the upstream business process or the oilfield. Current thinking has been to focus on the process.

There is a natural tendency by the organization that to assume that reduction of operation costs and capital exposure will improve the organization. It is common that by reducing operating expenses you may be forced to increase capital and vice versa. However, every change in the oilfield may have an affect upstream and downstream of the change.

- There is a perception that if you optimize a business process, you will improve the performance. It many cases this may be true. However, every operational business process has an almost limitless number of variances and constraints depending on the individual field
- As each oilfield is independent and unique, optimization should be done individually and the summarized in logical units.

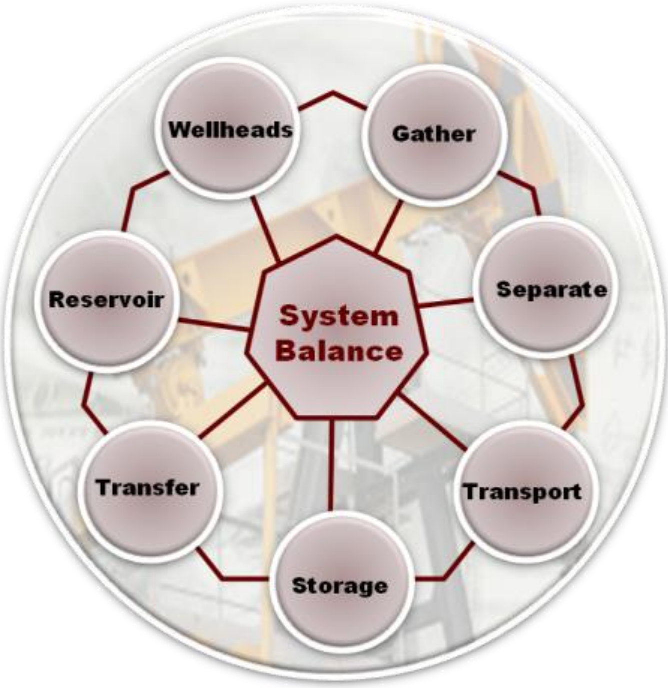

Diagram #3: Oilfield Balance

Understand the individual Oilfield Business Processes as they integrate with the oilfield lifecycle

- As an oilfield moves through the different phases of it's lifecycle particularly as the reservoirs and wells move further into the enhanced oil recovery processes, the water to oil ratio will increase sometimes dramatically. This fact alone can have a material impact on operating and capital costs. Further accuracy of production measurement the core process of product will be materially affected.
- As a field moves toward its end of life the revenue generated from the extraction of reserve volumes can quickly become indirectly proportionate to the expense to recover the reserve volumes.

Measurement is an early warning system for problems in the oilfield

- Proper production measurement and allocation is one of the best ways to monitor the reservoir or oilfield. If the KPI hydrocarbon allocation factor (HAF) is kept at or very near 1.000 along the flow of hydrocarbons from the wellhead to the transfer point, the HAF becomes an early warning system for operational problems. A slight change or variance at each point of measurement measured using the HAF is a warning to evaluate the change. This concept is very similar to the pressure drop (nodal) analysis that is commonly performed.

Leverage everything

- The answer quite simply is not always to always purchase the latest technology and equipment. Make use of everything around you that is available before making use the latest technology and equipment. Put another way, the latest computer technology improvement is usually important. However, why purchase this new power if the slide rule will work just fine. Very smart oilmen used the slide rule for decades.

Remember Substantive Decisions

- Plugging and Abandoning a field or reservoir should be done very carefully. The social and associated business costs can be dramatic. In the United States for every million dollar lost in production revenue by shutting in a field can cost 2 million in associated services revenue to maintain that production in the community.

Disposal costs planned and amortized 20-40 years ago probably are no longer relevent

- Disposal costs of disposing of a field can be dramatic. This is particularly true of offshore. It is rarely and accurately planned for when the field was originally opened

Criminals are smart and stupid; management of hydrocarbon theft

- The cost of proper security to protect the flow of hydrocarbons from the wellhead to the transfer point should always be related to the risk. The security of a casino is going to be vastly different than the security of your jewelry at home.
- It is a well documented fact that professional criminals will within a short time find ways to outsmart technology placed to stop them.
- A significant portion of theft is quietly supported from inside any organization
- Hydrocarbon theft is often times discovered due to sheer luck or an environmental spill

Operational Truths

- It is very common in brownfields for 80% of production volumes to be extracted from 20% of the wells. it is common that sometimes 50% or more of the wells within an oilfield will produce less than 10 tonnes of crude oil per month.

- Oilfields are not created equally and are not in the same place in their lifecycle. Therefore different oilfields require different levels of support to be successful as long as possible.

Production Measurement and Allocation

- It will not be discussed in this short whitepaper (unless requested) however it is well understood that the proper measurement across the entire oilfield provides critical data for operational management of the fields. This importance goes beyond just revenue recognition and affects almost every production operation process.

2. OVERVIEW

Optimization of the accuracy and uncertainty of the measurement of hydrocarbon volumes from the wellhead to the sales point and then properly allocating the volumes from the sales point upstream to the individual well or reservoir is a very complex undertaking for any upstream organization. The measurement is very difficult to understand, predict and model over the life of an oilfield. Inaccuracies can have a large effect both upstream and downstream of each meter. As a result, it is an immense management undertaking to manage and monitor the measurement of all these wells across the enterprise accurately in a repeatable and accurate manner over the lifetime of the fields.

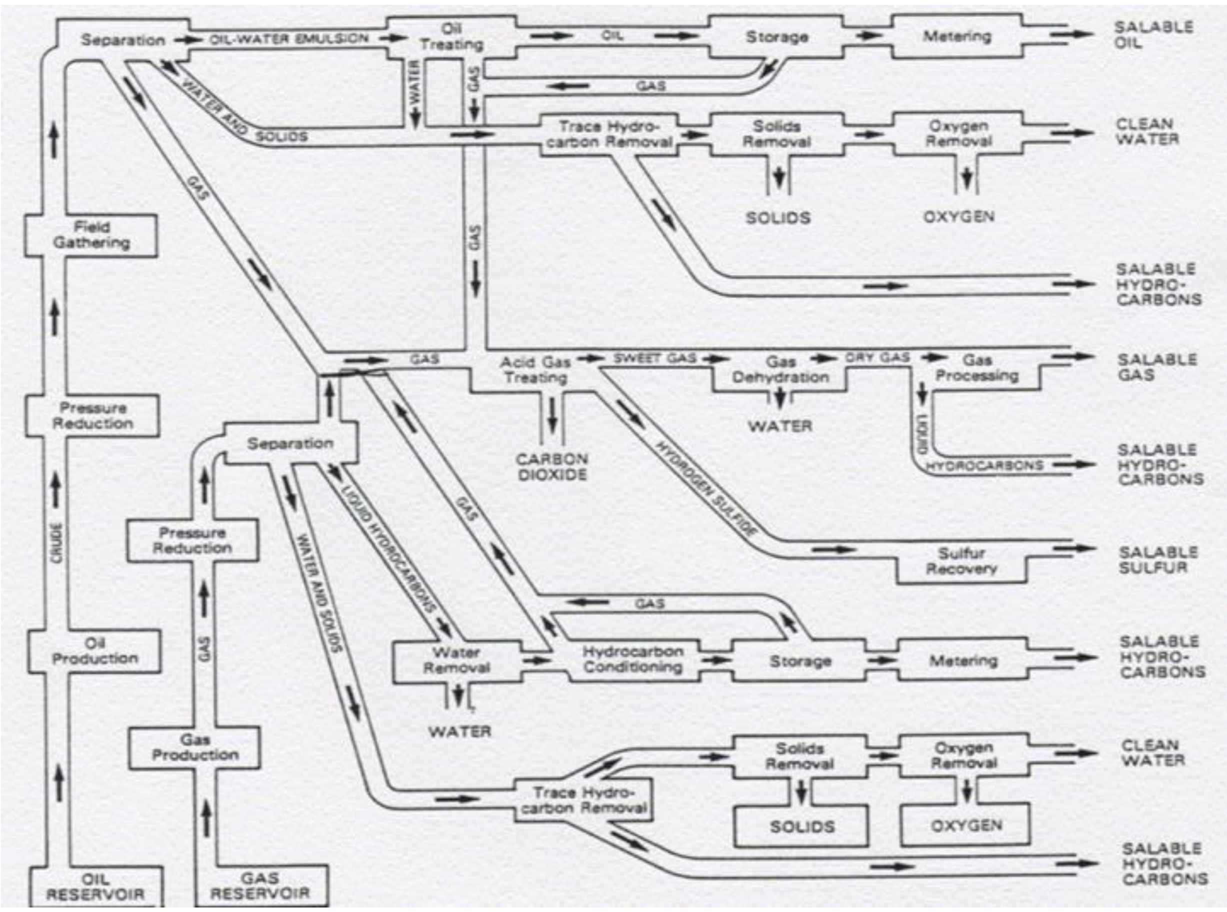

Diagram #4: A simple example of oilfield flow

 www.terralink-global.com info@terralink-global.com

Diagram 4: A simple example of oilfield flow provides a great example of the complexity of measuring hydrocarbon production. Consider the number of potential measurement points between the oil and gas production reservoir and the sales or transfer points. Now multiply this number by sometimes hundreds of reservoirs and oilfields within a production network. Finally multiply that number of the number of producing, injecting or disposing of the components of a multiphase flow.

To fully optimize every measurement point across the enterprise production network would be cost and labor intensive. In most cases the costs would far outweigh the benefits of implementation. So, the potential optimization must be properly balanced against other strategic and operational priorities.

3. A SLIGHTLY DIFFERENT STRATEGY OF MANAGING BROWNFIELDS

We believe that the best way to manage the large number of brownfields is to develop an innovative strategy that recognizes and manages the different levels of fields and reservoirs based on such things as production, reserves left in place, affect on higher producing wells within the reservoir etc. This strategy is to identify and segregate low performing wells and or reservoirs in terms of sustainability, production and profitability from the strategic and standard wells and reservoirs. *(See Schedule 1: A Typical Upstream field)*

Schedule 1 is a typical but real example of a brownfield and its associated wells. The starting point for for the model is the average volume per month. Using the average production for a month as a natural and initial separation point, our tool considers other information that would be supplied during an evaluation to model the affect current and future benefits of the well and reservoir. The category placement ideally will identify where management and focus should be placed.

Although it is not 100% the case, it is clearly understood that there should be different management and focus of the marginal and playout wells than strategic and possibly standard wells. This is for the benefit of all the categories of wells.

We believe this strategy may provide the best opportunities for the long term sustainability and profitability of the entire oilfield. This strategy will provide an opportunity for potential reduction risk from environmental spillage.

Schedule 1: a Typical field

Category	Prod Break Point	No of Wells	% of Wells
Strategic	> 1,000 T/M	12	12%
Managed	> 200 T/M	20	20%
Marginal	> 40 T/M	12	12%
Total		101	100%

In the United States there is a whole industry dedicated to the management of low producing wells. Low producing wells are called stripper wells and defined as those wells that are part of reservoirs are nearing the end of their useful life and produce less than 40 tonnes/month of crude. One out every 6 barrels of crude produced in the United States is now produced from stripper wells. Our proprietary Oilfield Well Optimization Model (OWOM) identification of the different segregation

The lower producing wells would be managed differently with different KPI's and performance management measures. At any given time could result in the following outcomes

1. Separation of the low producing assets from the main production system and accumulating production into a tank battery and possibly a separator. The accumulated production then can transported via truck to a terminal for processing or sale.
2. The hydrocarbons are accumulated and sold directly from the field tank battery and transferred by truck.
3. Accumulation and transfer through a separate low cost flow production system
4. The wells or reservoirs are sold to a thirds party. It is now very common that these end of life assets can be more efficiently managed by small local production companies that focus on this business
5. The reality is that many producing wells with no production and not associated with other higher producing wells in a reservoir should be plugged and abandoned.

The higher producing wells would have their own separate performance measurement standards however due to the higher level of performance for the organization would be able to look more closely at more expensive improvements.

In particular this strategy would allow the organization to focus on improving the production accuracy and allocation of the reservoirs and wells that are high producers and strategic. We believe instead of the understood number of about 26,000 wells. The number of high producing wells and reservoirs that might be affected by optimization would be far less than 10,000.

This change in business strategy has many operational benefits but it can significantly improve the management of the production measurement and allocation business processes.

4. A SIMPLE EXAMPLE

A relatively and relatively inexpensive example of a way to improve accuracy and uncertainty on higher flowing wells that are monitored daily is to use the noted information theory of Claude Shannon. Using the data streams from an oil well (pressure, temperature, flow, choke and travel etc) it is possible to scan the data for complexities (information complexity) individually or in combination. This information is scanned and a standard language is developed and understood during normal production operations. However if a specific operation or event is performed (examples may include methanol injection or production of a slug of gas or water) another language begins to be spoken. This would be the identification of an anomaly that may need to be investigated. Over a short period of time, these different languages could be used as a pre-curser to events that could affect the well or reservoir. Over a longer period of time this information and data could be accumulated to be used as a holistic monitor of the entire field and associated infrastructure.

5. QUESTION AND RESPONSES

Please provide ideas or experience to optimize the accuracy of hydrocarbon volumes from the field to the sales point.

The answer should include investigation and optimization of costs for purchasing different types of metering at different locations within the physical infrastructure of the flow hydrocarbons from the well to the sales point.

We cannot specifically identify the optimization alternatives that should be used without proper evaluation. We do not recommend the purchase and installation of any type of equipment or systems until a proper evaluation can be completed to understand the optimization alternatives and how they relate to each other. However we can offer some ideas that have been beneficial in other organizations.

Schedule II: Ideas for improving the accuracy of measurement

Idea/Implication	Comments
• **Standardization of Measurement Calculations**.	• One of the problems with accurate measurement is the number of different ways to calculate a given flow. Calculations of flow and methodologies should be standardized across the enterprise. • Multiphase flow from the wells is conventionally not metered in real time. In general, wells have uncertain multiphase production, and the level of production is conventionally measured using test separators and multiphase meters, nominally once a month Hence multiphase flows from the wells up to the initial bulk separators are usually not tracked in real time • Noisy liquid flow meter readings. It is common for some meters to consistently have dropouts and spikes due to gas bubbles, or density variation in liquid flows. In some cases, measurement noise for flow meter readings can easily be removed by applying simple linear filters to remove high frequency components. However, in other cases, the measurement signals are flooded with large fluctuations best characterized as spikes or dropouts. The fluctuations can have multiple sources: extreme sensitivity to changes in density, badly tuned level controllers, gas bubbles entrained in the liquid, compositional changes, measurement noise, and so on.
• **Nodal Analysis Across Production System**.	• Use nodal analysis to create a hydrocarbon allocation factor for significant measurement points that allow for identification of changes in flow quickly.
• **Stringent water cut analysis methodology**.	• Water cut should be determined using a common and stringent methodology. Differences of water cut between laboratory analysis and the field should be investigated and reconciled

Idea/Implication	Comments
• **Maintenance.**	• The production flow meters are not necessarily accurate. This can be due to a number of reasons, for example, meter wear, uncertainty in the density or viscosity or other properties of the fluids or a systematic drift in the electronics of the flow meters.
• **K-Factors not easily changed**.	• K-Factors that affect the meters should only be changed as recommended by the manufacturer
• **Correct sizing over time**.	• Piping and metering equipment should be monitored for changes in production rates
• **Pipeline and Tank Storage**.	• Emulsions within the flow-lines should understood and become part of the measurement and allocations • **Non-well related dynamic effects due to holding tanks and on-off pumps**. Dynamic effects due to storage tanks are addressed by simply including the level of the tanks in the computation of the flow balances. On the other hand, the effect on on-off pumps can be disruptive in that the changes in real time to well production will be significantly masked by the pump downs of the holding tanks. Finally: On-off pumps actually improve the certain capabilities as they introduce very useful regular variations over time.
• Include Transneft Meters	• Normally within transportation contracts there are a loss allowance that transportation contracts take advantage on
• Production Measurement process should be one process organizationally	• Many upstream organizations due to integration issues split the measurement process (wellhead to Trunkline and Trunkline to Sale) The process should be one continual integrated process to reduce the uncertainty!

Please provide indirect ways to monitor and control losses from spillage and theft.

This two part question has been gaining more and more interest within the upstream industry. Hydrocarbon spillage and its environmental effects have been a growing concern for the industry for a long time. Included in this discussion is the subject of the management of associated gas or the release of hydrocarbons into the air by accident or flaring. Unwanted negative publicity surrounding any found spillage into the environment quickly can grow into a regional, national and international political issue. Without diminishing the concerns surrounding this issue, it needs to be pointed out that natural seepage from naturally crevices create more actual spillage into the environment.

The second component of this question is related to the subject of theft of hydrocarbons. Considering the value of hydrocarbons in the world today, it there should be no surprise that there is a huge black market business in the theft of hydrocarbons. In Nigeria, it has recently reported that theft now accounts for almost 60,000 bbls of crude oil per day.

Hydrocarbon theft is usually carried out by two groups.

1. Enterprising local citizens who are simply trying to reduce the cost of living, keep heat in their homes and find ways to “tap” into the flow lines near their home.
2. Professional or semi-professional criminals who obtain the hydrocarbons illegally and sell them on the black market.

It is our experience globally that you will not eliminate theft of hydrocarbons. However it is possible to manage the theft, significantly reduce the stolen volumes and reduce the risk of environmental spillage. To eliminate potential theft at all points along an upstream company's hydrocarbon flow physical infrastructure would be extremely cost prohibitive without a long term guarantee of success. Further, it would put oilfield workers in harm's way in certain situations where the criminals may be offended by elimination of this revenue generator.

We believe in line with the general strategy established earlier in this document that the best way to manage theft and recognize potential spills is to manage the strategic assets. This means that a much higher priority should be placed on the protection of strategic or standard wells that account for the majority of revenue now and far into the future. While at the same time we would reduce the risk of the effects of spillage on the lower producing wells.

With all of the different wells (strategic, standard marginal and playout) tied into a production system, all wells must be monitored in the same manner to ensure success.

There are quiet or indirect and inexpensive ways to monitor the wells for spillage and theft, however they are usually not going to be sufficiently "real-time" to make a difference. These methods include production measurement balancing and pressure drop analysis.

Technology has advanced to such a point that here much more precise and real time opportunities that make it possible for quick response to spills and theft. These include fiber-optic technology and rarefaction wave technology. However, these technologies are expensive and are justified in only in high volume situations.

If the marginal or play out wells have been efficiently separated into a tank battery that includes proper environmental protection and proper physical management including measurement of tank levels, there is then opportunity to focus on improving the strategic and standard high flowing wells with better technology.

Schedule III: Security Comments

Ideas	Comments
• Oilfield Measurement analytical balance visualization	• This is a proven quick alarm for many operational situations including spillage and theft • In the best situation this is a warning system and not realistically real time enough to halt the spillage or theft. It can warn and reduce the effect of the issue • Economical
• Pressure drop analysis	• This is a proven quick alarm for many operational situations including spillage and theft • In the best situation this is a warning system and not realistically real time enough to halt the spillage or theft. It can warn and reduce the effect of the issue • Economical
• Using fiber optic technology to be detect subtle movements, heat changes, pressure changes around the flowlines	• Possibly the best new technology as it can identify movement, heat, pressure and liquidity. • Usually required to be placed across the entire pipeline and needs to be maintained • Could be bi-passed • Expensive
• Other technologies	• There are other new technologies that have proven to be successful on specific fields, yet have not become mainstream. These technologies tend to focus on offshore production

Please provide ideas or experience on ways to improve the accuracy of the hydrocarbon allocation factor and more meaningful to management.

The answer to this question was originally going to be part of the pilot project to be done in the Samara oil and gas company. The investigation of the reasons for possible inaccuracy of the Hydrocarbon Allocation Factor would be completed as part of the OLMF Methodology.

The original technical requirements included the following passages. "Within most upstream companies the primary Key Performance Indicator (KPI) for the measurement process is the Hydrocarbon Allocation Factor (HAF). The HAF is a ratio of allocation of hydrocarbon flow total inputs and total flow outputs at any given measurement point in the network. The ideal ratio is 1.000. HAF ratios can vary in the extreme from .6000 to over 2.18. The average appears to be in the high .80's which is close to the global average of .85 but far below the world class upstream organizations average of .97 and 1.03.

There is concern regarding reconciling large unexplained system gains/ loss variances between volumes measured at the wellhead by operations and volumes measured at different points of hydrocarbon transport and the final custody transfer points across the various production networks. Further given the very large number of measurement points along the network there is concern that performance improvement opportunities might be cost benefit justified for individual points but far less so if taken enterprise wide. "

From our experience, we understand that the Production Measurement and Allocation Business Processes are integrated yet independent. It is usually a five step high level process that quickly becomes extremely complex.

1. The measurement points of the flow of hydrocarbons as it is separated, stored, transported and used or re-injected into the reservoirs from the wellhead to the transfer point is a physical flow that usually includes almost entire physical system including infrastructure or equipment, pipelines, meters and human intervention.
2. Samples of hydrocarbons are taken at various points along the hydrocarbon flow transfer and evaluated either in the field, in the laboratory or both.
3. The transfer of the data from the field to the production area, subsidiary of enterprise head office that is used to calculate volumes that will be used for internal revenue recognition and regulatory requirements
4. The third process is the actual allocation of calculated volumes upstream from the transfer point to the wellhead. The allocation should include more than just crude liquids. There should be an accounting for all transferred. Re-injected or disposed products and bi products of the original hydrocarbon flow (usually multiphase) including but not limited to associated gas and water.
5. Reconciliation of any hydrocarbon allocation factor (HAF) issues that are encountered including signs of spillage and theft.

It is not our desire to offend any individual or group. However, given the wide range of values for the KPI of the Hydrocarbon Allocation Factor, it is highly probable that the inaccuracy is due to a number of inconsistently applied measurement sub-processes and tasks that are done within the oilfields and areas as well as the transfer of data to the department handling production allocations and finally the production department calculating the allocation back to the wellhead. The vast majority of these issues are unintentional and "hereditary". This means the process has always been done that way.

It is should never be forgotten that the reservoir hydrocarbon asset has a lifecycle that can usually be measured in decades and many changes to the field and infrastructure occur that would affect measurement and the subsequent allocation. Consistency of process standards, changes in the field and the measurement organization will account for the majority of the KPI value issues.

Finally, spillage and theft are always a concern of the producers. It should be noted that theft and spillage has made up a small percentage of HAF issues over the years. If there are issues with spillage or theft, it does not take a lot of math to understand that environmental spills and theft, even in small quantities can quickly generate large losses in terms of revenues, taxes, cleanup and social responsibility.

Below you will find an schedule and overview of potential ideas specifically as they relate to the hydrocarbon allocation factor, physical allocation and potential ways to mediate the risks and issues. The schedule is broken up into the five high level processes described above. It should be noted that some of the issues described earlier in this white paper are applicable to the response to this question.

Schedule IV: Allocation Comments

Process	Idea	Response
General	• Use of Russian Federation measurement standards and Internationally recognized standards	
	• Consistently applied calculation standards for multiphase volumes across the enterprise	
	• The Measurement process organization should be responsible for measurement of the entire flow of hydrocarbons from wellhead to the transfer point.	
	• The measurement and allocation should include the transport of volumes by the Transneft trunkline.	
	• Possibly the largest issue is inclusion, change or deletion of measurement points, wells, piping, meters or other infrastructure that should be included in the allocation	
Measurement	• The allocation system may not allow for the inclusion of an uncertainty value calculation on key meters. This is particularly important	This is particularly important for brownfield well that inherently have a large water to oil ratio.
	• Lack of strategy for managing volumes measured on a daily or more frequent time period with measurement points that are measured much more infrequently	
	• The inclusion in the allocation and calculations of production wells that have no production or very limited production combines to raise the uncertainty on high producing wells in the same production system.	
	• Pipeline levels with associated emulsions are not considered in the allocation even as a constant. Further many times as flowline diameters and chokes (with associated volumes) are changed in the field as production declines, the production office is not notified.	
	• Storage tanks levels are not properly measured	

Process	Idea	Response
	• Manual measurements are duplicated in the field, when weather or labor prevent the actual measurement of a flow meter.	
Sampling	• Sampling/ measurement standards and methodology are not consistently applied across the enterprise laboratories and the manual effort in the field	
	• Although, we are not performing an audit it should be noted that it is very common for the field personnel to manually alter the recommended "K" factor on the metering equipment	
Transfer	• This is commonly performed using excel spreadsheet flat files. The potential for error is quite high over a period of time. Once an error is made it is highly probable that it will become a "hereditary" part of the process.	
Allocation	• The production allocation system does not allow for changes in reservoir and infrastructure during the month. Such as placement in service of a well	
	• Once an error occurs and it is undetected , it almost always becomes "hereditary" and the error is made every time the allocation is done	
	• Many allocation systems do not allow for retroactive correction of volumes. As a result volumes may be over or understated for a time period.	

