Integrated Intelligent Operations & Production: Oil & Gas Developments

Volume 1

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Acknowledgments

With due credit to individuals, companies, contractors, and consultants mentioned throughout the text and pictures including technologies, products, and services from these and other entities doing really good work in the world of Digital Transformation – the Oil & Gas Industry is fortunate to be able to access so many of these solutions to help capture additional value from our developments

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1. Challenges for the Oil and Gas Industry

We have a number of challenges for our oil and gas industry in the current business environment:

- Uncertain oil and gas product pricing (ongoing significant movements) make forward pricing predictions more challenging, therefore risking future business cases;
- As a result of the recent oil price cycle, market pressures with reduced numbers of contractors, personnel, yards, and manufacturing may lead to increased unit costs for resources and products as the market continues to recover;
- Lessons learned from the recent oil pricing cycle require that life cycle costs need to be identified and challenged to help maintain sanctioned project business cases;
- Simplification of oil and gas development facilities and making them “connected” are needed to make them easier to operate and maintain, thereby requiring less manning with safer and more predictable operations;
- We need to extract the most value from our oil and gas reservoirs by optimising well designs and equipment/completion/production settings;
- Departure of aging workforces and availability of potential new employees more interested in technology can help drive adoption of improved technologies;

Integrated Intelligent Operations & Production (IIO&P) is a good methodology for capturing more value from our oil and gas development facilities. IIO&P is focussed on four areas:

1. Recoverability (Reservoirs);
2. Reliability;
3. Operability;
4. Maintainability.

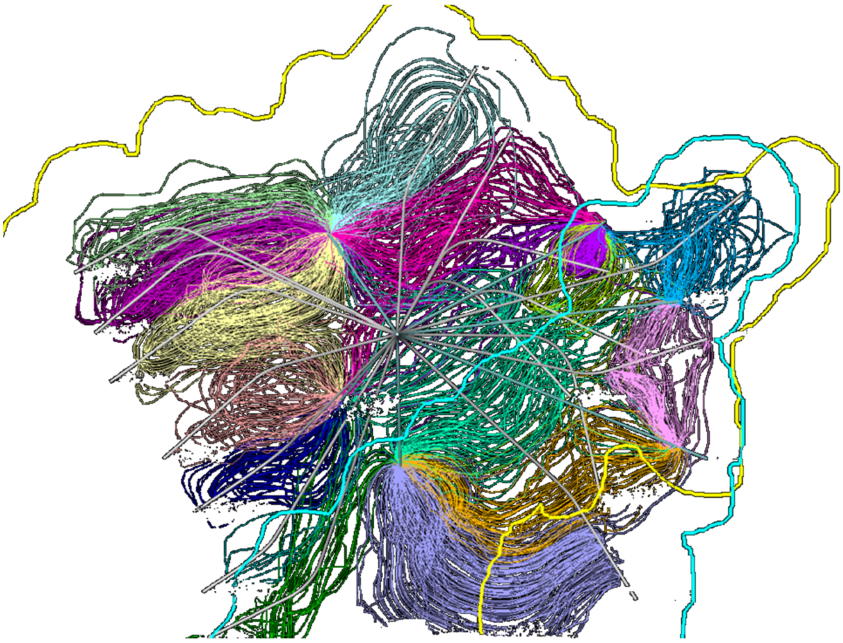
A good definition of IIO&P from Equinor (ex-Statoil actually) is that it is “Integration of people, process, and technology to make and execute better decisions quicker”.

An important reminder is that IIO&P is not just about inventions or new technology – it is about how these tools are adopted – another good quote, this time from Jeff Bezos, is that “Invention is not disruptive. It is customer adoption that is disruptive.” McKinsey & Company reminds us that “A digital transformation doesn’t stop at software updates or the introduction of new devices; it marks a fundamental change in how people work and how an organization delivers value.”

And unfortunately many companies have struggled to make the necessary cultural changes to properly capture the value available from IIO&P. I would like to talk about some of these challenges in this document and how they can be overcome.

2. Recoverability

Recoverability is about getting more hydrocarbon molecules out of the subsurface reservoirs. This is part of the Value side of a development's business case.



A common way of working previously was to obtain subsurface and production data from field measurements and manually run periodic reservoir simulations to check well and equipment settings and hence actual recoverability matched against predicted recoverability. There usually were significant time lags between receipt of field data, often unstructured manually recorded, its processing and checking by field personnel, and work by engineers in remote offices. People got in the habit of monthly or even quarterly updates and checks. These delays can result in leakage of Value due to inefficient production optimisation. IIO&P requires a cultural shift to work differently to capture this Value.

A complex reservoir could have various parameters needing to be measured and checked for these simulations. For example a reservoir could have production wells with tree production choke settings (affecting downhole drawdown and rates across the completions), and/or gas lift chokes (facilitating the production fluids ability to flow to surface), and/or subsurface hydraulic or electrical pumping systems. Water injection wells would have tree choke settings (affecting the amount of water injected into individual wells). Gas reinjection wells would have tree choke settings (affecting the amount of gas injected into individual wells). The subsurface reservoir could have different levels and compartments with a range of pressures, fluids, and rock properties intersected by different wells. A complex field development would need to have all these variables optimised and monitored more frequently to maximise the efficient recovery of hydrocarbons.

With current downhole and surface equipment IoT, digital data collection (with edge processing if required) is much easier. Data is able to be collected and moved with minimal latency up into the Cloud. Remote monitoring by operators, technical specialists, consultants, and equipment suppliers can use this data to perform much more frequent analytics.

Digital twins of the reservoir and associated production systems are able to be used. Numerical models are used to predict and characterise the dynamic reservoir behaviour and its controlling properties i.e. rock properties (porosity, permeability, reservoir architecture, heterogeneity etc.) and fluid properties (viscosity, relative permeability, GOR, bubble point etc.). Reservoir fluid conditions are modified by both pressure and temperature variation, i.e. (1) pressure drawdown adjacent to production wells; (2) over-pressure adjacent to water / gas injection wells; and (3) temperature variation adjacent to water injection wells etc. Detailed 3D geocellular reservoir models are used for reservoir simulations. Understanding and management of subsurface uncertainties via stochastic modelling is extremely important. However, for operational purpose, deterministic models (ranging from P_{90} to P_{50} to P_{10} resources, which refine during actual production results) are usually selected with continuous "tuning" performed. Results from selective time steps are extracted from the computer simulations. These results condition the reservoir input node(s) of the Digital Twin model.

Less than 5% of the data comes from the Subsurface but more than 95% of the Value comes from improved oil and gas production. Whilst the reliability of the production equipment and systems drives uptime / availability, it is the "tuning" of the subsurface models and real time operational adjustment of each well that offers the most potential Value enhancement through increased Recoverability. It has been estimated that 6-8% more recovery from a reservoir is possible by optimising these settings (earlier ramp-up, longer production plateau, and slower decline).

3. Cultural Challenges

There are significant cultural challenges associated with effective application of Integrated Intelligent Operations & Production (IIO&P).

In conferences I am sometimes asked about what kind of technology and equipment might be required for Digital Transformation. One person said he had bought a compressor for $2 million and he wanted to know how much extra a digital compressor would cost him. I told him that he already had the compressor capability, no further hardware expenditure was needed, it was the existing data stream coming from the instruments on that piece of equipment that needed to be utilised instead. Experts have estimated that up to ~99% of data from oil and gas facilities is not really used. Existing instruments collect data and typically stream it through control systems to local control rooms. Users might use some of this data for safety shutdown and simplified dashboard / control purposes. A big cultural challenge is to go beyond this superficial use and capture significant value inherent in the underutilised data. So IIO&P is not the hardware itself necessarily, it includes the proper use of data associated with the production streams being processed through this hardware – this requires a cultural change.

Siloed traditional organisations can contribute to this cultural challenge. Data related decisions need to be assigned to integrated asset teams closer to the information. McKinsey calls this an agile organisation. A major international oil company had an offshore development where subsea well and floating facility data streams were separated and directed to different teams located remote from each other and the asset. Reservoir engineers did not work with subsea engineering teams who did not work with topsides facilities engineering teams. Each team looked at their own data, remote from the daily field operations, so it became numbers and masses of data unable to be holistically optimised. Reservoir engineers would make some periodic analyses of their reservoir simulations (usually not frequent enough) and try to vary subsea well settings (i.e. chokes, gas lift parameters, water injection parameters, etc.) to optimise production, but the resulting flow could sometimes lead to subsea flow assurance issues (i.e. slugging, hydrates, difficulty in start-up, etc.) that would not immediately be identified. Subsea engineering teams could adjust well flows through manifolds into flowlines to balance flow rates or manage start-up cooling/warm-up, but topside equipment might require different allocations of well fluids for better control of hydrodynamic slugging (gas fluctuations) or other process requirements.

The point is that the development (wells + subsea + floating facilities) needs to be optimised holistically as a system, ideally using a Digital Twin. A small multidiscipline asset team with subsurface as well as facilities personnel can receive field data and perform the necessary data analytics to optimise recovery from the field as well as operate the subsea and topsides equipment safely and more efficiently. Functional support or corporate teams can still have some periodic oversight and assurance role, but an agile team close to the asset will deliver much more value – working closely with the field personnel, this is the essence of IIO&P.

Unfortunately, many organisations struggle with this concept and "fail" to deliver the benefits of digital transformation and wonder why not. They designed the hardware, they bought all the software, they connected it to the Cloud, they contracted data analytics – but it was not integrated and it was not timely and responsive to changing information from the field. Value is captured by decisions; decisions come from insights; insights come from analytics; and analytics run on data collected – the process needs to start from the desired value end of this equation. Some developments have gathered masses of data (expensive and sometimes not even to the required fidelity to properly analyse), run lots of analytics (sometime remotely and delayed, not on the Edge where some short term streaming actions could deliver better value), obtained a lot of information, but then it was not properly utilised. Different kinds of people are needed in the agile teams to use this data – this is not a pure IT/IM project, it is not a pure engineering project, it is not a pure operations exercise – these diverse teams can have people who never worked in oil and gas developments, of different genders, ages, and experience, with different cultural backgrounds. The Harvard Business Review says "diverse teams are smarter" and "conformity discourages innovative thinking". This way of thinking needs wider management adoption to help ensure the success of digital transformation. Other industries are way ahead of our oil and gas industry but we can be "fast followers".

4. Reliability

A common question asked of most asset teams is “How can we obtain better reliability of our wells, process equipment, and production systems?” A proper answer to this question involves starting to address this challenge quite early in the life cycle of a development when engineering and procurement is in early stages. Reliability is not something you just “bolt on” later in project phases.

Improvements start early in front end engineering design for developments. Reliable production systems need simplified designs (less things to fail or have complicated operating requirements which could lead to uneven performance) with more robust equipment (higher Mean Time between Failure (MTBF)) and appropriate levels of redundancy. The cheapest, low bid piece of equipment or system might not have the required reliability to deliver best overall life cycle costs. Experience from other projects and industry (“lessons learned”) is important when developing functional design specifications for equipment and evaluating proposals from suppliers. Choosing suppliers successfully used previously in an asset team would help field personnel deliver more predictable maintenance which improves reliability by fixing equipment right the first time.

During engineering of the development, designs should be checked against a range of operating inputs and scenarios (reservoir fluid compositions, properties, rates that may vary during the life of the facility). There have been major projects in our industry where only the maximum nameplate operating parameters were checked with inadequate appreciation of start-up, ramp-up, varying reservoir fluids, and upset conditions. All the key design properties have some chance to vary depending on the reservoir – liquid hydrocarbons can vary somewhat in viscosity, API gravity, wax, and other compositional properties. Reservoirs can have compositional gradients over the depth and area of the reservoirs (e.g. compartments). Gas can vary in amounts (including breakthrough of free gas). Reservoir water can vary in salinity, scaling, and produced rates (breakthrough again). Slugging can mean that liquid slugs from certain types of well designs can come through to the production equipment causing upsets. Increasing gas cuts (or gas lift amounts) can lead with hydrodynamic slugging (gas fluctuation) again causing process upsets. Unanalysed operating inputs and conditions will commonly lead to problems with reliability.

“Flawless” is a big area that I will address in more detail in a later section of this document, but for purposes here it includes defect elimination during Procurement (Vendor supplied equipment and systems) and better delivery during Construction and Commissioning (dependable QA/QC, vessel and piping cleanliness, valve/instrument/rotating equipment management, as-built documentation). Getting equipment and systems properly pre-commissioned and commissioned with adequate testing time durations, high enough pressures and temperatures more similar to operating conditions, and with fluids and flow rates closer to design requirements helps ensure equipment is more reliable in the field. Extra time in a shipyard or fabrication yard can save an operating team much more significant operating time and value out in the field. And getting the operations team involved in this final work onshore on its own leads to significant improvements in reliability during operations by ensuring equipment is properly connected and tested. “Flawless” is a culture, that done properly, means that digital twins are able to more properly analyse and model the facility (wells + subsea + production equipment) and anticipate equipment and systems performance and degradation. There is a good API document addressing some of this subject called API RP 1FSC “Facilities Systems Completion Planning and Execution”.

So a checklist for increasing reliability would be: (1) Simplify Systems; (2) Use Quality Specifications; (3) Select Robust Equipment (high MTBF); (4) Ensure Defect Elimination; (5) Pursue Flawless Start-up; (6) Incorporate Open Standards; (7) Use Performance Monitoring; (8) Use Remote Diagnostics; and (9) Perform Descriptive / Predictive / Prescriptive / Cognitive Analytics. Increased Reliability means being proactive, not reactive, and having the systems (wells + subsea + production equipment) be properly physically prepared and ready to be monitored for performance during life. Reliability issues often occur where predictability is not present. We want to understand our systems well enough to anticipate issues and proactively prevent or mitigate these issues prior to any production upsets.

5. Operability

Another question from those hard-pressed Asset teams: "How can we find the best way to operate our process equipment and production systems?" Once again, it involves starting earlier in the whole life cycle process. Operations teams cannot always improve their asset operations without having had significant help in early engineering design and procurement phases. We have to set up our facilities and their Operations teams for success.

To start, engineers have to get operational input (including sizing and ratings) from potential suppliers for a range of specified operating conditions. Most equipment and systems have better operating envelopes where they are easier to control (more stable) with better performance and less degradation (reduced wear and tear). Engineers cannot always rely on operating on the margins of equipment capabilities. Control systems are automated for many operating scenarios, but using equipment on the edge of stable performance envelopes likely means a lot of manual intervention and tweaking of control logic settings. Control systems have better and worse ways of starting, ramping up and down, and stopping equipment - and systems and operators need this input from the suppliers to improve Operability.

One of the most important tools in the Design phase is the use of Engineering Simulators. Using dynamic process simulations combined with control systems (ICSS) emulation with logic checks means that the safety and control systems can be better designed. These systems can be checked to see if they are going to work in the field as envisaged in the design. In past projects onshore and offshore, we have seen Operations teams spending up to a couple of months tweaking control systems logic and timing to ensure stable (uninterrupted) operations particularly when dealing with start-ups and process cycles. These interruptions can represent significant lost value. Having theoretical desktop reviews of control systems is not good enough anymore and it is not required with the use of these Engineering Simulators.

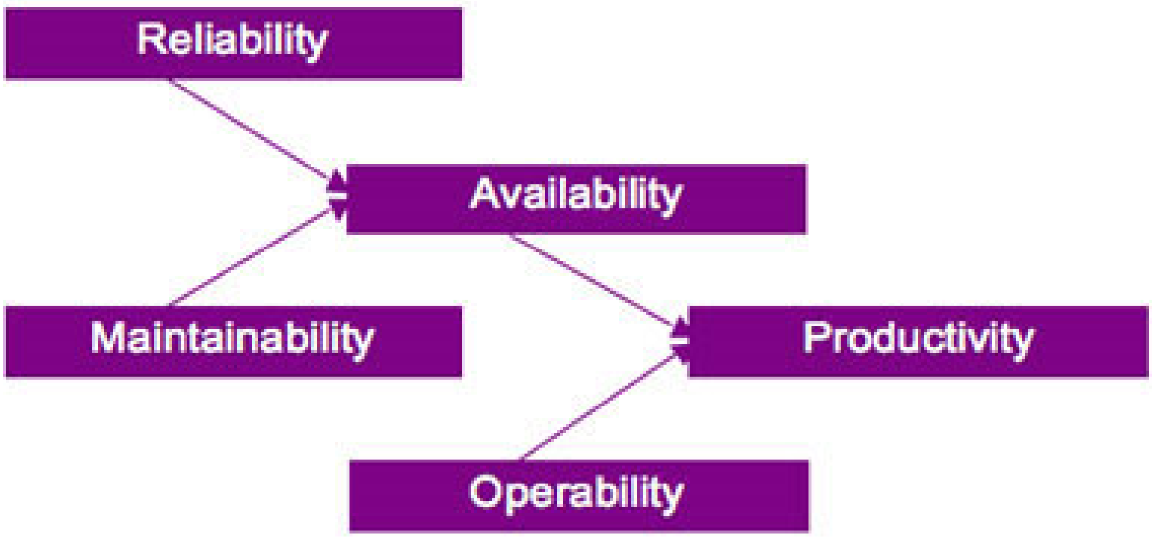
Digital Twins in Construction and Operations Training phases are a big part of increased Operability. Digital Twins are powerful tools for analysis, design engineering, training, and operations. Their starting basis is the Engineering Simulators from Design. They are enhanced with as-built Vendor data to improve equipment parameters, and then we input pre-commissioning / commissioning performance data. These dynamic simulators become much better digital representations of the real world physical systems. Then they can be used to build Operational Training Simulators (OTS) for training of Operational crews. We need to perform this office training as early as possible, since we need to mobilise Operational teams to the onshore fabrication and integration yards prior to completion of the facilities. First however, these OTS are office tested by the field knowledge brought to the technical challenge by the Operations team – supplementing the Engineering team's often more theoretical knowledge. Field experience has shown that skilled operators can help with suggestions about exact equipment set-ups to get ready for start-ups as well as knowledge of how some timing of valve closures, control valve settings, and rotating equipment parameters should be adjusted to avoid pressure surges or gas fluctuations that might interrupt operations. The use of OTS also helps improve the overall competency of multiple shifts of Operations teams so that best practice is planned and trained and maintained.

Digital Twins in the Operations phase ("connected" production facilities) are where this tool then continues to improve Operability and deliver real value. The Digital Twin is (1) updated to match actual in-service condition of equipment and systems (from sensors/IoT); (2) updated with actual well and production fluid data (composition, properties, rates from field testing and metering); and (3) updated with relevant operating procedures to stay within "safe to operate" Integrity Operating Windows (ref. API RP 584 "Integrity Operating Windows"). Updated, relevant Digital Twins ensure field Operations teams are best supported by remote Asset teams with both teams able to use these models (compared to field data) to see how actual field operations are proceeding. Any adjustments to deal with changing field conditions (whether from the reservoir fluids or from equipment/systems degradation) can be proactively dealt with in an easier collaborative manner, thereby improving Operability.

6. Maintainability

Another question from Asset Teams: "How can we find the best way to maintain our process equipment and production systems?" By now you understand a general theme of IIO&P, it once again involves starting earlier in the whole life cycle process. Maintenance teams cannot usually improve the maintenance of their assets without having had significant help in earlier development phases. An obvious philosophy is to help set up our facilities and their Maintenance teams for success.

Safety & Environment and Operational Critical Equipment (SECE and OCE) in a production facility need to be identified early in a development in order to determine the necessary assurance and integrity programs. The maintenance of this equipment is critical for increased safety and value. This equipment needs special preparation and attention. Maintenance has to be "designed in" up front – providing the needed physical access and material handling, tools, training, competencies, ease of removal, plug & play, and spare locations. The degree of redundancy, numbers, and types of spares has to have been a risked decision considering MTBF, maintenance timing, ease of maintenance, and location of maintenance (on the skid, on the facility, in a shore base, or removed and repaired remotely).



A comprehensive database of video training recordings by Vendor specialists should be made available for training, demonstrating best practice procedures for use by multiskilled field crews. These recordings can be made during manufacturing FAT and SIT work whilst the actual equipment is available. Otherwise training videos can be made during final pre-commissioning and commissioning in onshore fabrication or integration yards prior to field installation. Virtual Reality training is where these training videos are supplemented with computer simulated models of the equipment or systems in a simulated physical setting. Maintenance personnel can then see the physical constraints to disassemble and remove equipment parts as maintenance is performed. Correct sequences of disassembly and especially reassembly can be shown and practiced in a virtual setting, thereby better preparing the worker for the field work. These simulations also help prepare workers in ensuring the proper tools are used and any methods of using specialist tools. Augmented Reality guidance is when the field maintenance is actually being performed – maintenance personnel can be in audio-visual contact with remote technical experts who can provide real time coaching or guidance for particularly complex maintenance or diagnostics. There will be more content on both of these types of training in later sections of this document.

The use of an intelligent 3D CAD Model with linked Contextual Database containing all equipment design data, vendor data, operational data (including online and historical process data), maintenance details (spares, tools, procedures, competencies, etc.) is part of getting ready to safely maintain critical equipment and systems. Maintenance preparation should be done "digitally" prior to anybody physically leaving the safety of living areas and going out to the site of the equipment. Poor productivity or incorrectly performed maintenance is often due to lack of preparation, inadequate training on the required tools and spare parts, and failure to properly understand the necessary isolations and physical constraints to perform the work. The old axiom "If you fail to plan, you plan to fail" is once again applicable – resulting in potentially unsafe maintenance or interruptions of production and loss of value.

Specialist sensors need to be incorporated into the designs in order to monitor leading indicators of piping, equipment, and systems "degradation". With an aggregated database of this information, we can perform cognitive analytics i.e. determining what is changing (and how) that should not be changing, given the particular process conditions (inlets, outlets) and facility conditions (motions, environment). Data analytics on SECE and OCE should allow predictive maintenance by monitoring this degradation of performance – maintenance intervals can expand or contract as required based on actual performance. Again, this topic will be explored in depth later in this document.

7. IIO&P Topics

The list below is quite detailed, but anybody less familiar with these topics should not get concerned about how much this will cost. Most of the higher cost hardware and systems already exist in our facilities. This is not some big shopping list that will cost a lot of new investment. Most of the data involved is already passing through our systems, but it is not being used typically (McKinsey says ~99% of IoT data is unused to help with analytics, insights, decisions, and value). The biggest challenge is people and culture as discussed in a previous section. We should not assume that existing people and organisations will seamlessly shift over to this IIO&P world. It will take adjustments in culture and the use of more diverse collaborative teams than may have been involved in previous "analogue" or "manual" operations. There is a high incidence of failure of digital transformation efforts when management has not appreciated these people and culture challenges.

Some of the topics that will be covered in this document from an oil and gas development perspective:

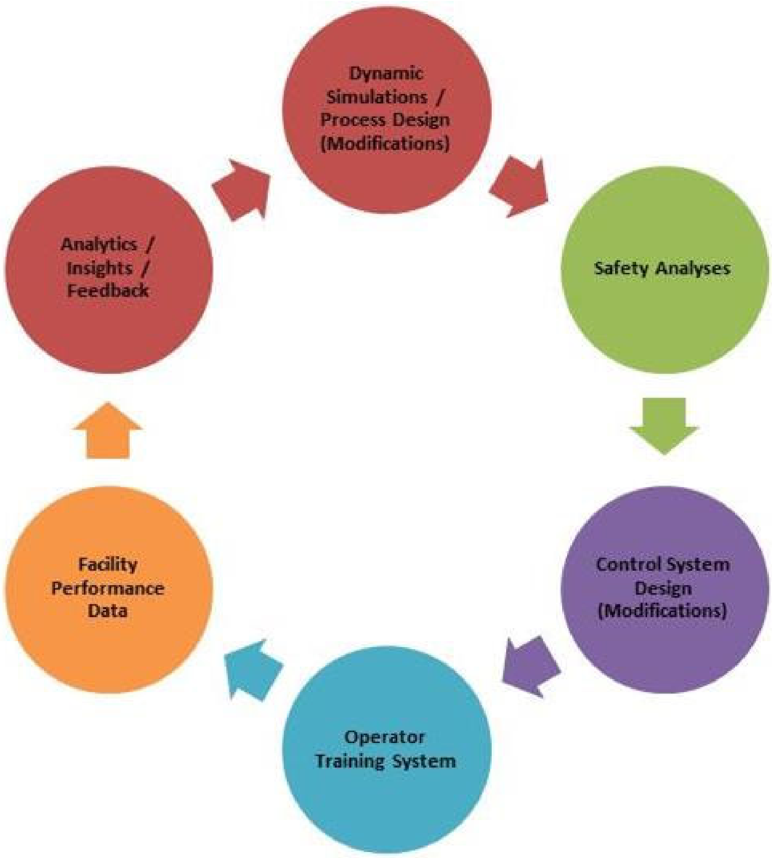
1. Safety and IIO&P;
2. Digitization, Digitalization, Digital Transformation, IIO&P – "Being Connected";
3. Agile Teams (diverse collaborative teams helping to best focus the application and delivery of IIOP);
4. Flawless Delivery and Start-up;
5. Internet of Things (IoT);
6. Sensors (including digitalising what could have been observed, heard, felt, or otherwise sensed);
7. Physical data (including deflections, excursions, tensions, vibrations, or hydrodynamic motions);
8. System Architectures (how the data flows from IoT through all the systems and users);
9. Communications (telemetry including Copper, Fibre Optic, Cellular, Data Radio, Microwave, or Satellite);
10. Remote Monitoring and Diagnostics;
11. Big Data (including Data Catalogues, Data Lakes, Data Warehouses, and Data Platforms);
12. Blockchain;
13. Data Analytics (Rules);
14. Data Analytics (Descriptive, Predictive, Prescriptive, Preventative, Cognitive);
15. Artificial Intelligence (AI) / Machine Learning;
16. Application Programming Interfaces (API's) (extracting Data and performing Data Analytics);
17. Data Analytics;
18. "Cloud / Fog / Mist" – What does this mean in the IoT Data World?;
19. Digital Twins (Data, Process, Physical);
20. Integrated Production Management System (IPMS);
21. Operational Training Simulators (OTS);
22. Integrity Operating Windows;
23. Virtual Reality (VR);
24. Augmented Reality (AR);
25. Maintenance;
26. Robotics;
27. Subsurface IIO&P;
28. Subsea IIO&P;
29. Cybersecurity.

8. Safety and IIO&P

Improved safety is a major benefit of digital transformation. Instead of being reactive and mitigative, we have the opportunity to be proactive and preventative. Part of technical safety is about understanding how our wells, equipment, and systems are functioning, especially with respect to upsets or abnormal performance that could lead to loss of containment. Having better monitoring and diagnosis of this performance gives us more insight ahead of time that something needs attention, adjustment, or even shutdown.

Linked with AI/Machine Learning we can track upsets or trips over the life of a particular facility and "learn" combinations of parameters that lead to upsets, sometimes in nonintuitive ways that may not be readily noted by human operators. Control systems have logic to track some parameters for high or low excursions outside programmed boundaries that require intervention, either automatic or manual, but these systems will not necessarily catch all holistic scenarios that could lead to safety issues.

With the help of normal safety and control instrumentation supplemented by a few specialist IoT sensors (i.e. digitised monitoring of visual, thermal, vibration, motions, etc. where applicable) we could capture data to better understand potential degradation of safety and other preventative barriers that need to be understood to avoid surprises.



Safety Improvement Cycle with IIO&P

The best design efforts can have unexpected field process responses in early production unless there has been better dynamic simulation models used with control system emulation prior to any actual hydrocarbons being processed. As mentioned in a previous section, historically there have been several months at the start of production in many facilities where the control systems logic had to be modified to align better with field conditions and facility responses (i.e. pressure surges and variations during start-up, ramp up, valve changes, and shutdowns). Some of these issues could have had safety risks associated that are now able to be worked better ahead of time with these simulations in the office prior to field production, so the facilities would be safer.

An analytical review in the North Sea of human operator actions in response to various process situations associated with gas compression showed clear differences between "good" responses and "variable outcome" responses. Operator training should have achieved alignment with desired responses, but some operators were observed to modify reactive responses for unclear reasons, and it was observed that some sequences of control responses more often led to trips and compressor shutdowns. Best of class operational training should use Operations Training Simulators (OTS) to standardise "desired" operational practices (kept updated over time on a facility especially if there are improvements or necessary changes). Then using Digital Twins (and data analytics), linked to actual process conditions and control event monitoring, would show when any operational responses were deviating from the desired responses and assist operators by either helping point out preferred responses or in some scenarios giving warnings or even "block" (or require supervisory approval of) any riskier actions. More predicable production operations are inherently safer especially if we are operating in more ideal integrity operating windows.

Field personnel are busy and more physically at risk when they are in the field, so they should be supported by remote technical teams in operator, contractor, consultant, or equipment supplier offices. Routine data analytics should be ideally performed in real-time and "Edge" (on the equipment or skids), but if they require to be run offline, they should be done by these remote support teams with information fed back to the field personnel. This would help ensure information and any required actions were less likely to be missed or skipped, thereby improving safety. Support from remote teams can be provided through augmented reality to the field personnel to help them perform any necessary actions quicker and safer including preventative maintenance.

Safety is our priority to take care of field personnel, neighbouring communities, and to protect the environment from any release of containment of hydrocarbons. Inherent safety is the best form of technical safety where we are not relying on human intervention. We need our risk reduction measures to move from procedural mitigation to active control to passive prevention finally to eliminating hazards. IIO&P and digital transformation offers this opportunity starting in design and leading into safer field operations.

9. Digitization, Digitalization, Digital Transformation, IIO&P – Being "Connected"

Sometimes confusing terminology explained:

• Digitization – creation of data in digital form, it can be either structured (readouts from instruments) and unstructured (i.e. reports), often characterised by conversion of information from an analogue to digital format;

• Digitalization – using digitized data to generate more information in the form of KPI's, dashboards, or simplified summaries, but otherwise not being used to generate value, this is the start of the development of digital workflows;

• Digital Transformation – better use of digitized data to generate value through optimisation of automation and certain types of data analytics;

• Integrated Intelligent Operations & Production - new work processes and ways of performing oil and gas operations and production, facilitated by cultural improvements and using digital transformation together with better connectivity, collaboration, and integration.

(Ref. "Digital Transformation on Purpose" G. Unruh, D. Kiron, MIT Sloan Management Review, November 2017)

"Connected" is a shorter term that is increasingly popular – it means connected in a broader sense than just the communications. It signifies operational teams at remote production facilities connected to diverse, collaborative support teams spread anywhere internationally. It means all aspects of the system from reservoirs to wells to surfaces facilities to production facilities are holistically connected through data flows to all the stakeholders from field operations to remote teams. It means all these stakeholders are able to perform analytics and share insights, make decisions, and capture value together. Over and over, we read about the importance of people, process, and technology being connected and integrated to help make and execute better decisions quicker – this is Integrated Intelligent Operations & Production (IIO&P).

Much of the Digitization is already done in our oil and gas industry. Unstructured data is making significant advances in being able to be captured and better utilized. AI systems like IBM Watson are being used by companies like Woodside to capture value from unstructured data contained in over 600,000 pages of documentation.

Digitalization is pretty common with dashboards to take raw operational data and applying structure and context to the data streams. Systems like OSIsoft PI are used by the top ten oil and gas companies centralising data from real-time process automation systems.

Digital Transformation has been the next step with technology enabling the industry to build on the first two “D”’s – the masses of data crossing our systems needs to be used, not just superficially noted. There is significant value to be realised by using the data – don’t be reactive, be proactive – review, analyse, and make plans on how to utilise the information obtained. Not data for data’s sake, but selected data, prepared, and accessed by those ready to extract the information. Analytics have exploded in popularity and ease as users have realised the benefits to be proactive. And these analytics don’t just have to be performed offline at some remote location – they can be programed into our equipment and local computational resources to perform real time “Edge” analytics. Edge analytics allow more rapid automation decisions at the data source to correct problems or optimise performance instead of waiting for operators to get notifications and perform these adjustments with some time lag.

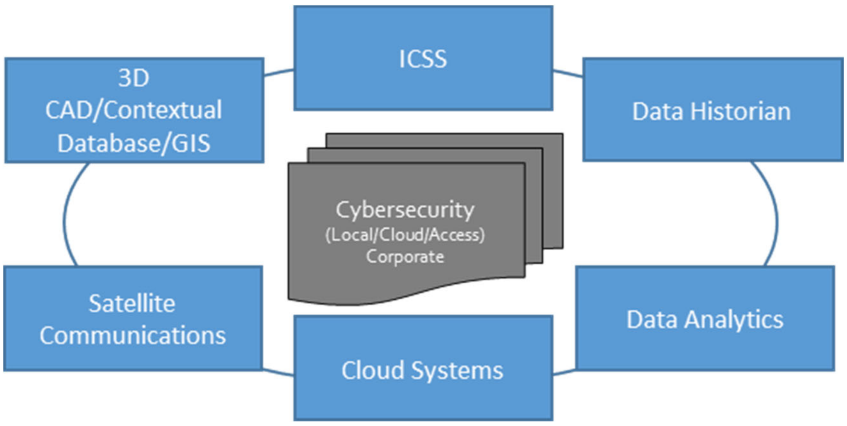
Previous sections talked about Integrated Intelligent Operations and Production improving Safety, Reliability, Operability, and Maintainability. This improvement comes from deeper use of the data and most importantly preparing the design, the facilities, and the working culture to be ready to obtain the data, perform the analytics, realise the insights, make decisions, and capture the value. Integration is the key, not just being intelligent, but connecting users and expertise and systems in a more rapid seamless manner. This isn’t some “bolt on” piece of technology or software. Hard drives full of useless, incorrect fidelity or frequency data are similarly a waste of time. The physical facility has to be suitable to be analysed in a way linked to real performance so that excursions or aberrations can be spotted and resolved. Powerful results come from the adoption of IIO&P. But there is a high incidence of failure where people went into this process not really serious about changing how they connect and work.

10. Agile Teams to Deliver IIO&P

How can an organization best deliver a digital transformation to their way of working? The use of "Agile" Teams has been found to be a good way to make these changes. "Agile" is a term from the software industry. Agile Teams are small, diverse, cross-functional, and collaborative. These teams are populated from oil and gas facility owners, contractors, engineering consultancies, suppliers, and service companies including engineers, planners, IT/IM, and operators. A specific mindset is required for the people and teams:

The Agile Mindset	
People	**Teams**
Enjoy collaborating	Embrace change to pursue and capture value
Communicate openly	Welcome diverse thinking
Willingly share knowledge	Practice transparency
Are interested in learning	Work at a sustainable pace
Take pride in outcomes	Identify and correct whatever is not working
Have fun at work	Use failure as a learning opportunity

With support across an organisation, multiple small Agile Teams would pick a number of initial IIO&P related subjects for potential consideration, customisation, and delivery. An example of a small initial selection of subjects is shown in this figure (and each subject will be better explained in future sections). A given is that the choices must be selected with a view towards effective cybersecurity.



Aspirational targets/outcomes from the selection and applications of technologies in each of these areas should be driven by operational needs. But most of all, the work culture and processes to benefit from these choices must also be identified for successful implementation.

In the actual collaborative work of these Agile Teams, short "sprints" of work would be incremented with results driving subsequent activities and new task cycles. This is a different way of working from traditional oil and gas projects, so management needs to be aware that the process is different when expectations and schedules are being set.

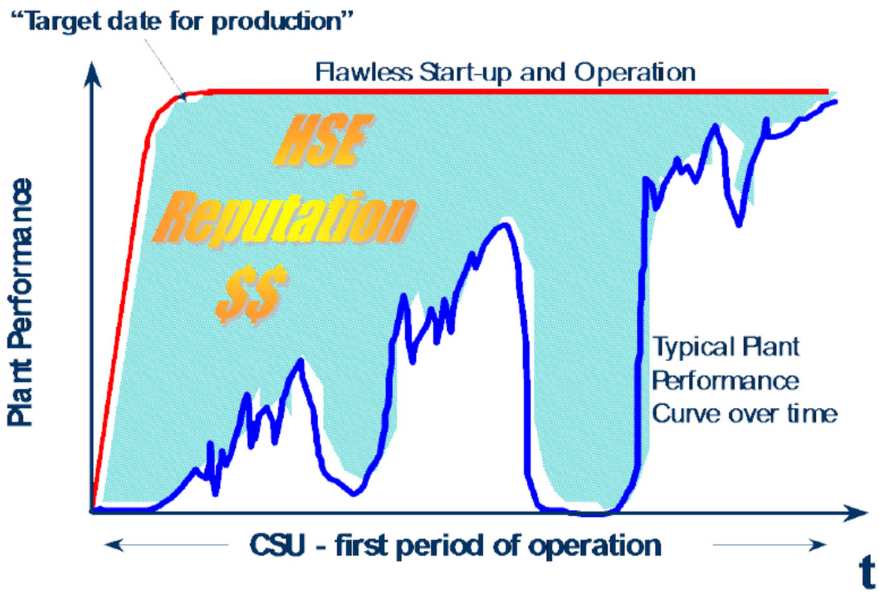
Fortunately for us in the oil & gas industry, we can be “fast followers” and see what has been done in other industries to solve the challenges to capture more value. Handling data and connecting widely spread, diverse users for example is pretty common practice now so there are good practices and technologies to adopt and apply. The technology is not usually the challenge however – getting work practices changed to extract the maximum benefit will be a key challenge of these Agile Teams. How can field personnel best be selected, trained, and linked collaboratively with remote experts? It includes finding ways to analyse data quickly and feeding back insights and decisions to field operations and maintenance personnel in a timely manner to be proactive not just reactive. Material delays in making changes in response to data are effectively a hidden loss of value or downtime. Reduced recovery from reservoirs or equipment breaking before changes can be made to how they are operated is something these Agile Teams can address in selecting people, technologies, work procedures, and culture.

Agile Teams’ IIO&P decisions about technology should be input into Functional Design Specifications and Design Philosophies, and then implemented by Asset Teams who understand the corresponding procedural changes. Agile Teams can be a key part of the successful delivery of IIO&P.

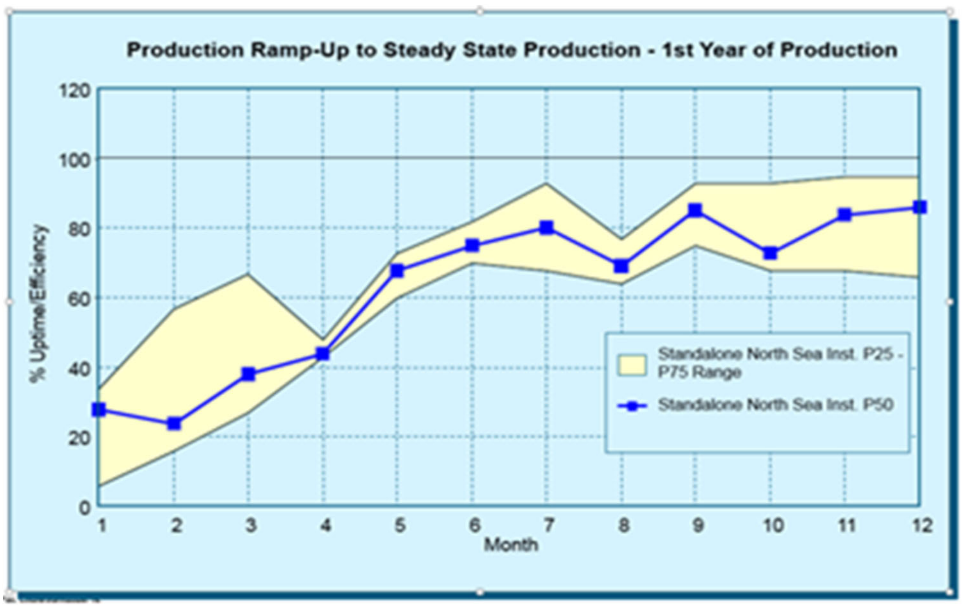
11. Flawless Delivery and Start-up

This section describes the concept of Flawless Delivery and Start-up. "Flawless" is a term that came into popular use some years ago associated with Shell's Flawless Start-up initiative but it has evolved to be associated with Flawless Delivery of Facilities encompassing Start-up into Operations. Our industry is challenged to do a better job in completing our oil and gas facilities, starting them up, and successfully operating them.

Two illustrations below show the challenge: (1) a graph used by Shell to show how much difference a Flawless Start-up makes to Plant Performance in the first period of operation for typical plants; and (2) a curve from the U.K. North Sea showing % Uptime Efficiency per month in the first 12 months of operation of installations illustrating actual P_{50} Production Ramp-up to Steady State Production. In both examples, significant loss of value is shown – in the range of hundreds of millions of dollars for large developments. "Flawless" is how we attempt to close these gaps to optimise performance efficiency and capture this value.



(*Ref. Shell*)



(*Ref. OGA*)

Flawless starts in Concept Select (pre-FEED) phase when Design Philosophies are developed and the Concept is determined from the various choices. It continues into Define Phase (FEED) and through FID/Sanction into the Execute Phase (Detailed Design, Procurement, Fabrication, Pre-Commissioning, Commissioning, and Start-up) and finally into Operations. It involves all disciplines and all activities – everyone has to have the mindset to consider and apply Lessons Learned from previous similar projects and facilities. Once procurement and fabrication starts, it involves finishing tasks in the appropriate location by the people best capable of completing the work – in other words, don't pass along punchlist items to others who may be less capable of understanding, keeping track of, and/or completing the work. Flawless relies on delivering a fully completed physical asset that will function as designed and analysed.

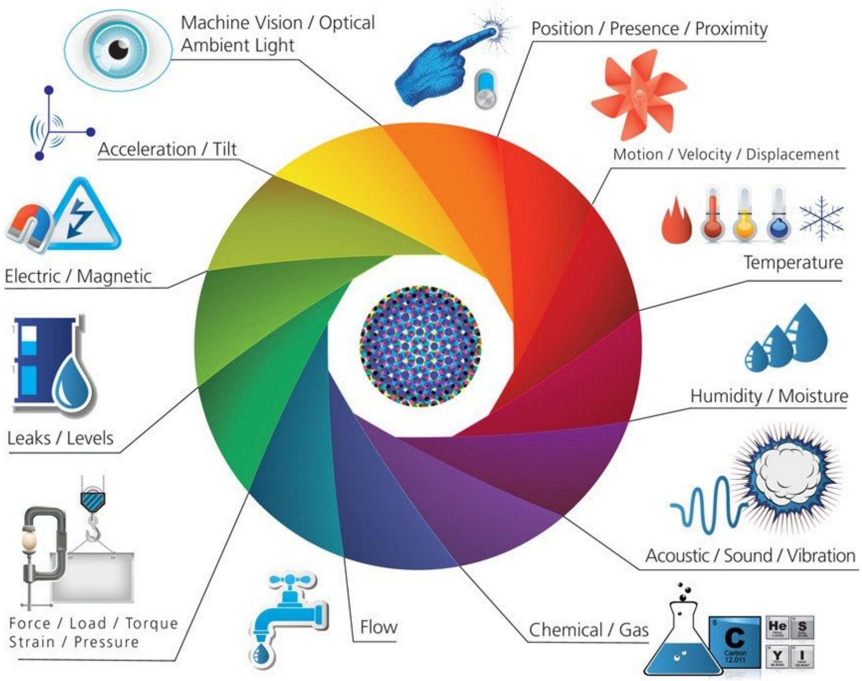
Q1 – Tightness
Q2 – Cleanliness
Q3 - Integrity
Q4 - Operability/Maintainability
Q5 - Preservation
Q6 - Prototypes
Q7 - Complex Systems
Q8 – Testing
Q9 - Experience
Q10 - Coinciding Events
Q11 - Integration
Q12 - Information

There are twelve (12) "Q Areas" of performance that are critical to a successful Flawless program. The delivery of required quality in each of these areas is impacted by decisions about people, organisations, technical, commercial and contractual matters taken throughout all project phases. Monitoring against KPIs during the entire lifecycle of a development and systematically making continual adjustments and corrections helps ensure that the different Area performances deliver the necessary outcomes. But make no mistake "Flawless" is as much about culture as it is a process. Individuals and teams throughout the entire Development from Engineering to Supply Chain to Construction to Operations need to be committed to the Flawless program for it to be successful. Detailed procedures exist across our industry to help plan a Flawless program – one partial set is contained in API RP 1FSC "Facilities Systems Completion Planning and Execution" (1st Edition, July 2013).

Once an oil and gas production facility has been delivered in a Flawless manner, benefits are noticeable and material. Ramping-up production as per the original business case delivers obvious value, but longer term the facilities will be operating as designed and theoretically analysed. At this point, the use of Digital Twins becomes important as monitors and predictors of performance – these dynamic simulation models are configured to be able to model the physical plant and track actual performance against theoretical performance. We need to be able to ensure the physical facilities are being properly operated (within optimal performance envelopes) and we need to be able to monitor and correctly react to any changes in inlet production streams (oil, gas, and water – rates, temperatures, pressures, compositions). The physical facility needs to perform as designed and analysed – it cannot be randomly encountering issues related to pre-existing defects or partially completed systems and therefore performing randomly. Flawless helps eliminate this randomness and improves predictability.

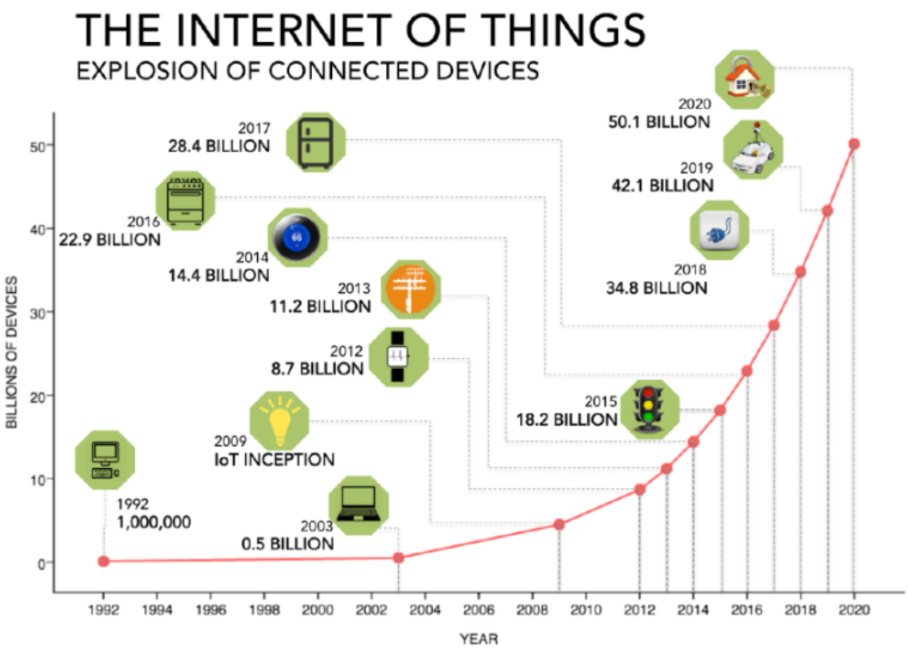
12. Internet of Things (IoT)

Most of you have heard of this phrase or abbreviation – it encompasses a wide range of connected sensors or devices. IoT is a network of physical devices able to be connected through the Internet, discoverable, and able to process, share, and receive data (as per the types below):

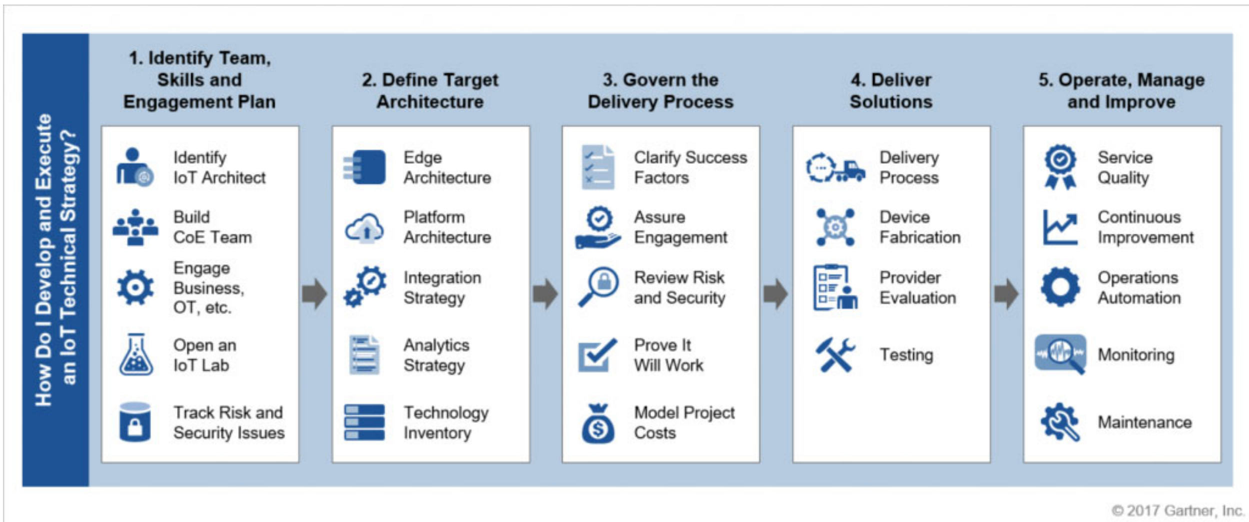


Types of Data to be obtained from IoT Devices

The number of connected devices in the world is usually estimated with significant variance, but the number appears headed for the hundreds of billions. McKinsey estimates a total potential economic benefit impact of multiple $Trillions. The oil & gas industry has noticed and progress is being made to capture the value from using IoT in an integrated development strategy like IIO&P.



For the oil & gas industry the most common example of IoT is all the safety and control instrumentation in wells, in facility equipment and systems, and in flowlines/pipelines. IoT can also include RFID tags, wearable sensors, audio-visual, motion sensors, sampling devices, and drones – the picture above shows some more examples. IoT devices have a sensing layer where sensors are integrated with the hardware, a networking layer where data is able to be transmitted through wired and wireless networks, a service layer which helps run user requirements, and an interface layer to provide a way for users and applications to interact. IoT is the way data is collected and connected to users and applications. There are barriers to adoption which can include challenges of interoperability with legacy systems, lack of technical expertise on the solutions and methods needed to maximise the value, the challenge to transition from a more analogue manual data world, and cybersecurity.

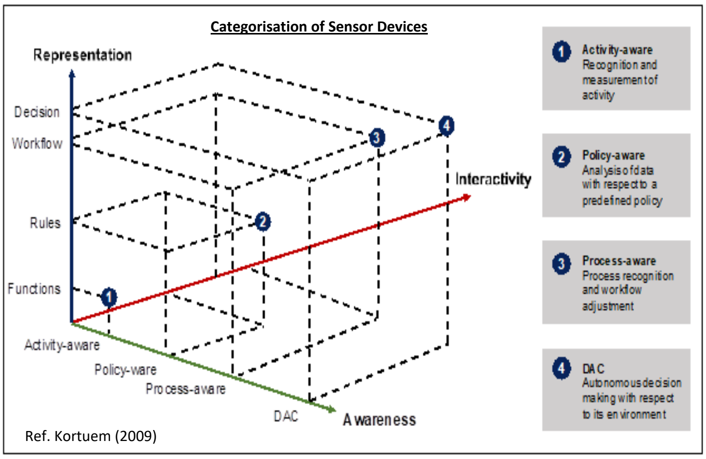


The Gartner graphic above can be somewhat intimidating, but there are good consultancies and service companies to provide the resources and expertise to perform this work. Being a "fast follower" is a good strategy for many companies. And for operators, our contractors are very competitive, so solutions using the strategies above are constantly being developed and made available to the market.

So can our oil & gas industry face these challenges, overcome the barriers, and find a way to best utilise all the possibilities inherent with increased use of IoT? Judging by the amount of technical articles and presentations available online, there are a lot of good individuals and companies chasing this "prize" pretty hard, many of whom appear to have the imagination and skills necessary on how to collect and better use these data streams to perform analytics, find insights, make decisions, and capture value.

13. Sensors

Sensors were discussed briefly in the last section on IoT. Sensors are one way we capture data – they can capture structured or unstructured data. They can be connected through wires or fibres, or they can be connected wirelessly. "Smart" sensors can be a variety of types, standalone or integrated into hardware:



One of the critical safety risks and value drivers in our oil and gas industry is the exposure of humans to the production and process equipment environment and hydrocarbons inherent here. An operator in an oil and gas production or processing facility makes use of many senses. If personnel are placed in a safer control room away from the facility, their "field senses" could be replaced with electronic sensors. These sensors could provide the remote operator with the comparable information that they would experience if they were physically walking around a facility. Key human senses, used to supplement the normal safety and control systems data, which are used in facilities monitoring ("rounds") and control and which can be automated, are:

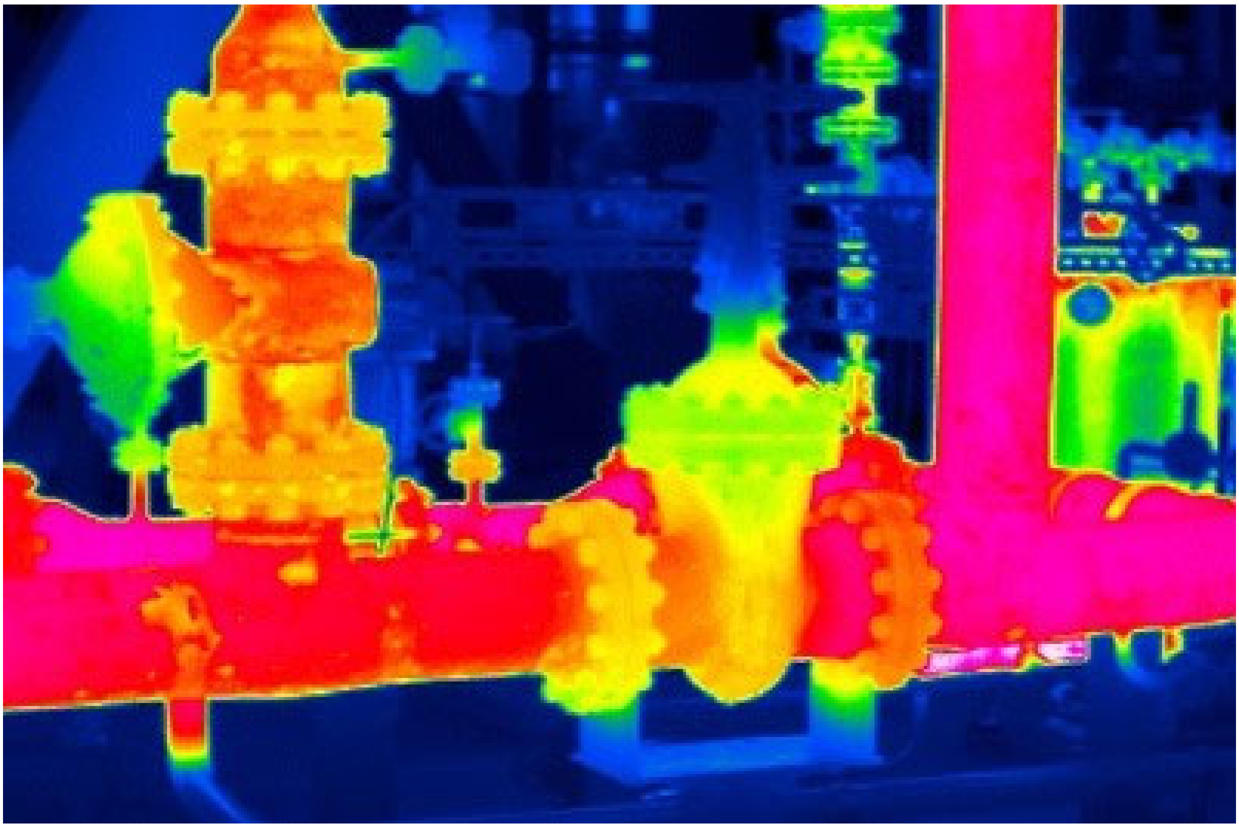
- Sight - by use of cameras, infrared/laser scanners, and motion detectors (i.e. ultrasonic, infrared, microwave) coupled to automatic detection software recognising anomalies to raise alarms;
- Hearing - by use of microphones, acoustic emission analysis devices, and vibration analysis devices;
- Smell - by online air analysis devices, smoke detection devices, fluid monitoring devices (i.e. gas, oil, water, chemical flow analyses);
- Touch – thermoception (heat or cold, temperature contact sensors or by infrared devices), resistance (weights/tightness/torque resistance), and or the use of load cells and strain gauges measuring weights and stress/strain levels;
- Balance and acceleration - by use of facility motion and vibration sensors, and accelerometers.

These sensors could be coupled to analytics recognising anomalies/trends to raise alarms for the operators' attention, either remote or locally. Sensors should be connected to data historian software and platforms to monitor and record trending and histories of all sensor data. Some data should be collected in real time; other data could be dumped in non-critical path times. Sensors should be connected to various data pathways – hard wired, fibre optic, wireless etc. – with multiple paths for critical data and priorities for certain data in the case of any degradation of data paths. Sensor update timings should be variably adjusted based on trend analyses (i.e. changing data can be checked more frequently where critical or alarmed e.g. alarm based on rate of rise).

Sensors can be constrained in physical size, computational power, memory, bandwidth, power consumption, and the environments where they function. Security of information capture and transmission to secure networks is also important. Finally cost can be a driver in their utilisation and numbers. Thankfully technology in miniaturisation has been making smaller, less power intensive, increased computing power sensors available to us, so their use has tremendously increased their role as IoT in IIO&P data capture and analytics.

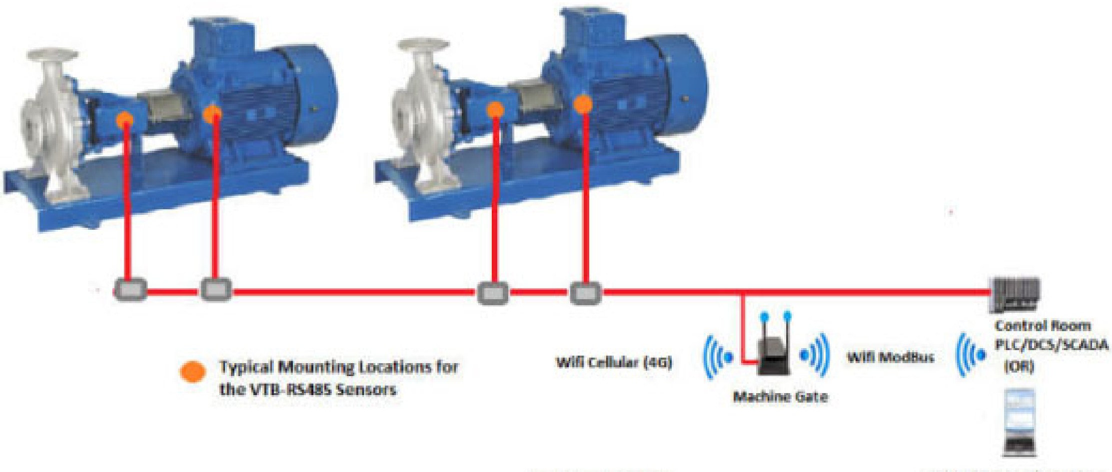
Virtual sensors can also be a way to help overcome some of the constraints. The used of tuned Digital Twins, built on the flawlessly delivered facility, can provide predicted data at various locations in a production or process system without there being a physical sensor at that location. Virtual sensors can also provide backup for physical sensors to facilitate fault detection and to allow routine maintenance of defective instruments in planned or normal shutdowns instead of having to shut down just for maintenance.

Sensors can gather information to help make our facilities safer, operate more smoothly, help with preventative maintenance, and help us be better connected to our IIO&P oil and gas facility.



Thermal Imaging of Process Systems

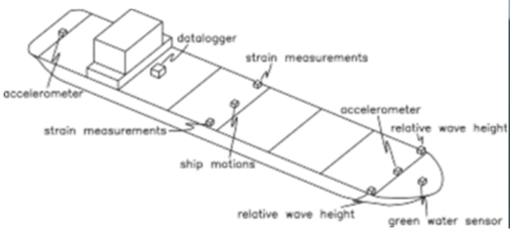
Visual and Infrared Camera Devices

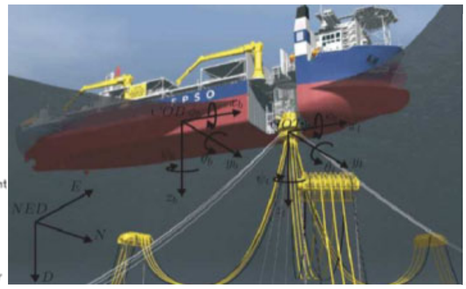


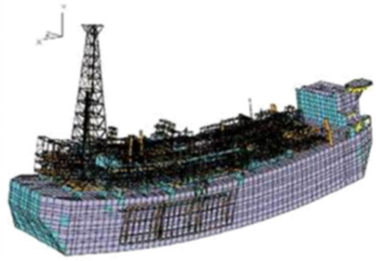
Vibration Sensors

14. Physical Data for IIO&P

Physical data (including deflections, excursions, tensions, strains, vibrations, or hydrodynamic motions) is able to be captured by IoT sensors and used to help improve safety and reduce cost with IIO&P. Floating oil & gas facilities have physical data that is able to be collected to be used in several types of analytics:







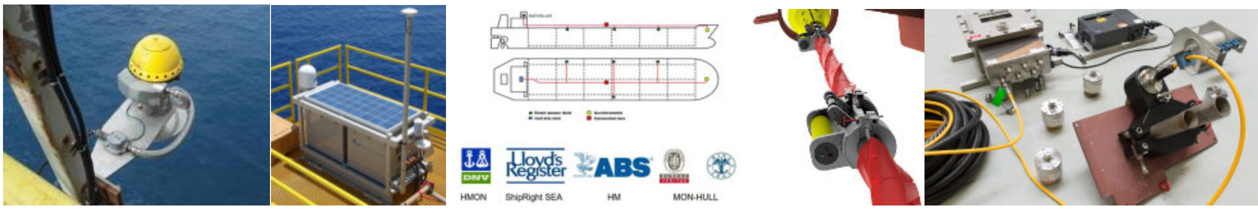
- Predicted hydrodynamic motions (roll, pitch, yaw, surge, sway, heave) are used in naval architecture calculations for vessel strength and fatigue – but we are able to measure actual motions for comparative analyses – and we can tune our simulations to better predict motions from given metocean conditions;
- Excursions of moored facilities can be measure to check the design of risers and umbilicals and stiffness of the mooring systems themselves; actual tensions of mooring chains, cables, or ropes are important to check integrity and any degradation of these critical elements;
- Strains in key physical components can be measure to calculate stresses which are able to be used to check and maintain records of physical integrity including fatigue performance;
- Vibration of equipment and support structures can be an early indicator of maintenance problems developing or even process issues (cavitation or control valve fluctuations);

Large floating oil & gas facilities including FPSO's, TLPS's, Semisubmersibles, and SPAR's can have so many compartments to be regularly inspected that either large numbers of crew (and expensive access) are required or some form of robotic inspection equipment needs to be used to be able to gather and record physical data in order to monitor the need for fabric maintenance. In ballast tanks this equipment can be mini-ROV's capturing visual data like coating breakdown or fatigue cracks. In storage tanks this equipment can be drones flown around the inside capturing visual data similar to the ballast tank inspections. The visual data could be linked to 3D CAD models, so that contextual locational data could be maintained and processed automatically in comparative analytics looking for changes that may require human intervention or remediation as part of risk based inspection programs.

Another way physical data can be used for FPSO's is through monitoring vessel motions with respect to vessel heading. Analytical models of observed metocean conditions are able to be used to predict if any heading change could improve vessel motions to facilitate helicopter operations, supply vessel operations, or even effectiveness of process separation equipment. There was an FPSO in the North Sea that had certain motion characteristics where oil/water sloshing inside the production separators led to out of spec crude which ended up having to be offloaded, transported, and cleaned up in Rotterdam prior to marketing – this lost significant value. But many FPSO's have thrusters which could be used coupled with the motion analytics to either automatically modify the vessel heading or recommend heading changes to the vessel crew in order to reduce adverse motions.

During FPSO offload operations with stern/tandem positioned shuttle tankers (either with a taut hawser or DP aligned) the relative motions of each vessel need to be monitored carefully to maintain safe working envelopes. Automatic analytics programs receiving absolute and relative motion and positional data combined with real-time metocean data can provide much safer operational performance, either automatically with linked thrusters or by providing better real-time input to the marine crews.

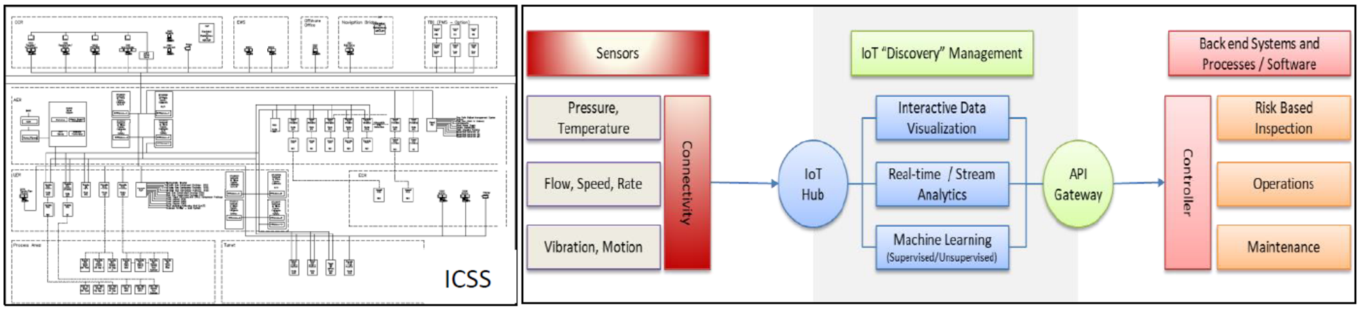
Another extreme example of motion monitoring and heading adjustment is floating facilities exposed to hurricanes or cyclones. As these extreme storms approach a facility, they are often downmanned (or should be!) but they may have difficulties maintaining best heading without thruster assistance. The facility would tend to weathervane as the wind shifts but as a result the prevailing seastate direction could become quartering or even beam seas which might lead to damaging greenwater on the deck causing damage to the facility. Automatic analytics programs could once again work together with linked thrusters to maintain best headings.



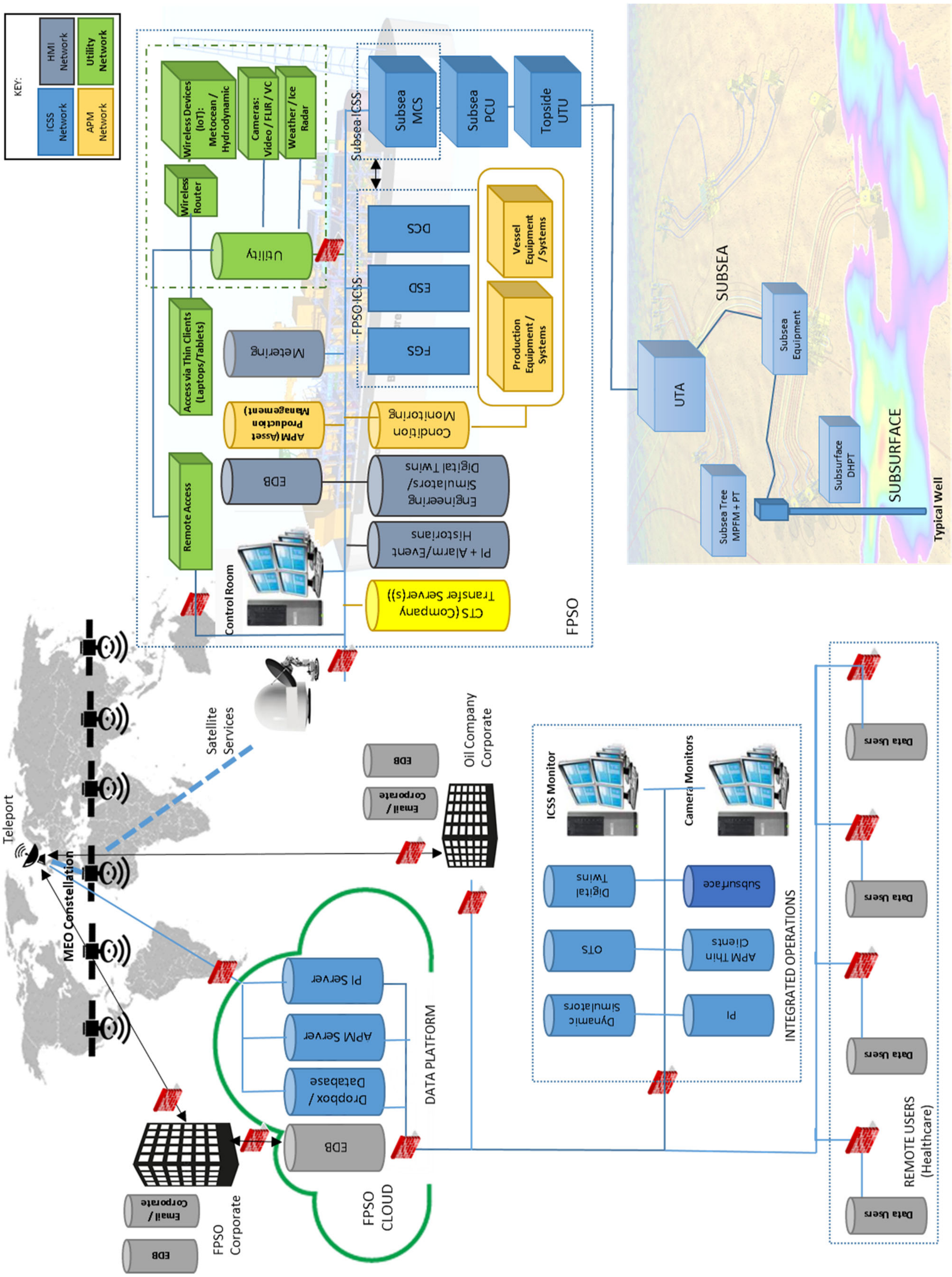
Physical Data Sensors

15. System Architecture

"System Architecture" helps explain how data flows from IoT through all the systems and to all the users. Previous sections of this document have described the types of local instruments or IoT devices and the type of data measured, observed, collected, and used. One of the most common initial pathways for this data in our oil & gas facilities is the normal safety and control systems already present. Hard wired with high integrity levels (SIL) these systems connect safety and control hardware with equipment to allow monitoring and control where needed for safety (e.g. shutdowns) or process adjustment (e.g. opening and closing valves or power for motors or pumps). But once these data streams reach the Control Room (or E-house); the "System Architecture" has only just begun in the world of IIO&P.



Historically most of our data flowed by and was only marginally utilised (McKinsey: "<1% used"). Onsite or field operators would have periodically monitored the data in real time and some dashboard usage meant that certain fidelity data was stored and could be accessed to look at trends or incidents. But as we have learned, the main use of data is for analytics – ideally online, real time, maybe on the "Edge" (on equipment or systems) – but very powerful remote analytics are possible and this means the data needs to be collected (in the necessary fidelity) and conveyed to networks for remote users and computer systems. For many onshore or nearshore facilities, this pathway could be hard wired (copper or fibre optic), but for remote and offshore facilities (like an FPSO shown below), the pathway could be through satellites up into the Cloud (e.g. Data Platforms) and onwards to users:

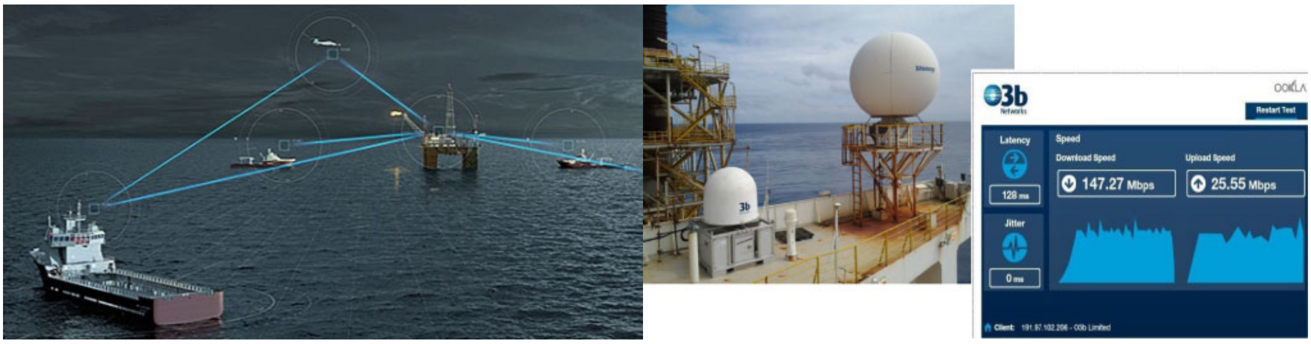


Nominal System Architecture for FPSO with Subsea Wells

16. Communications

Communications (telemetry including Copper, Fibre Optic, Cellular, Data Radio, Microwave, or Satellite) were shown on the previous section's sketch of System Architecture for IIO&P. The bandwidth and latency of whatever communications path is selected are critical to the choices of information flow and desired actions/reactions.

Where oil and gas facilities are located in more developed locations, it has been possible to run hard wired communication systems, either copper cables or more frequently fibre optic (i.e. BP GoM Fiber Optic Network, multiple users, delivers up to 100 Gbps with <20 ms round trip latency; and North Sea Communications AS / TampNett AS / Central North Sea Fibre Telecommunications systems now interlinked with latency <4.3 ms).

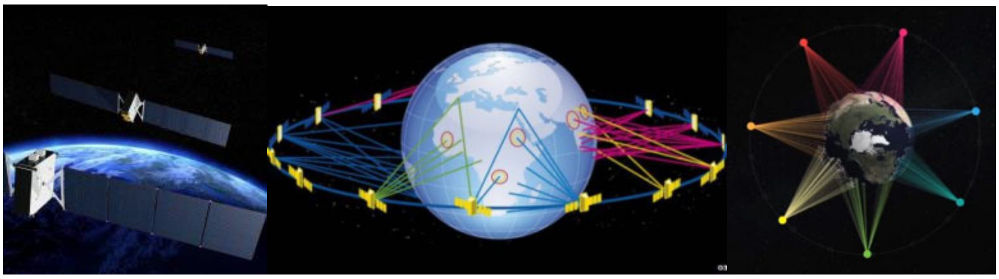


As a way to distribute connectivity throughout a facility or among adjacent facilities including vessels, 4G LTE service has been available through offshore base stations connected back to shore with fibre networks. Wi-Fi can be used to distribute connectivity through a facility, but distances and the amount of steel structure and piping can affect coverage. Wireless devices using 2.4 GHz band are commonly used for larger distances whilst the 5 GHz band has better penetration through facilities but shorter range. Some companies have begun to deploy private 5G cellular networks which have better wireless connectivity in such environments plus latency less than 1 millisecond. Where wireless connectivity is not required, conventional wide area networks with Ethernet connections are hard wired within many facilities.

Maritime Broadband Radio operates in the 5 GHz band that uses beamforming steerable high-gain omnidirectional antennas relatively unaffected by vessel movements. Its operational range is around 50km (sea level) with low latency for data up to 16.5 Mbps, so it could be part of an integrated solution especially for distributed connectivity.

Microwave radio systems with gyro-stabilized antennas (4 to 18 GHz) are being used onboard FPSO's offshore Brazil. FPSO's can weathervane or move with significant motions so that the antennas need to be able to adjust to the movements in order to maintain line-of-sight radio contact. When vessels rotate, the stabilized antennas would compensate in order to maintain 0.2 degree of accuracy. Latency is estimated at <5 milliseconds.

Satellite communications have progressed thanks to all the other industries. Technology choices including frequencies (C (4-8 GHz), Ku (12-18 GHz), and Ka (26-40 GHz) bands), antennas, and types of satellites (low earth orbit LEO, medium earth orbit MEO, and geostationary orbit GEO) have allowed great advances in use at much lower costs than only a few years ago. Bandwidths and latency vary with the types of satellite systems, so users can determine their data needs (upload and download) and work with providers to determine primary and backup system needs. The FPSO example in the System Architecture section showed a high capacity MEO system.



There are good choices for communications to improve IIO&P connectivity and many sources of this expertise.

17. Remote Monitoring and Diagnostics

Oil and gas facilities are challenged for the cost of operations and maintenance. It can be costly to have large field operations teams and getting specialist maintenance personnel to visit in a timely manner can be difficult. An earlier section covered the safety reasons for reducing the numbers of personnel exposed to potential hazards. Fortunately we have significant amounts of technology and successful applications available to help us overcome these challenges.

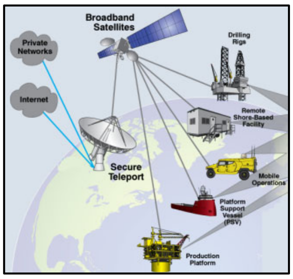
Examples of successful remote monitoring and diagnostics can easily be seen in the space industry (e.g. unmanned probes to Mars or the Moon). In our oil & gas industry we have long distance subsea tiebacks where everything has to be done remotely on the seabed where there are no operations teams.

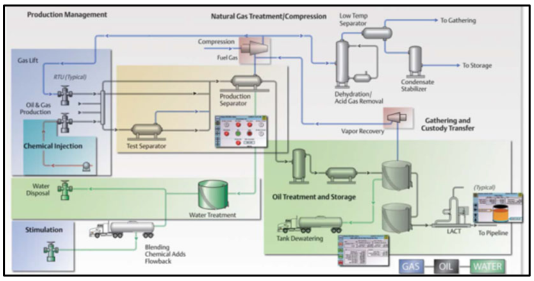
Remote monitoring is facilitated through the previously described use of IoT devices and instruments interconnected with users via communication systems discussed previously. Real-time monitoring should facilitate continuous optimisation of the production process efficiency. Instruments should facilitate early detection of issues or confirmation of changes to optimal operating conditions ("exception based surveillance") where required. Latency may be an issue for remote sensing with time and response delays associated with the means of communication, so for critical operations or facilities, there may always be a need for some amount of minimal manning. But the aspiration of "unmanned" or "not normally manned" is a good driver to simplify equipment and systems, deliver them flawlessly, then perform effective remote monitoring and make changes to the way a facility is operated if needed.

Remote diagnostics covers a wide range of things from direct shared personal communications to edge analytics to offline analytics in the Cloud. Remote diagnostics on critical systems adds to the ability to conference technical issues with appropriate remote centres of excellence (i.e. SME's or specialists) to ensure that any decision made is of the highest quality, worked in a collaborative manner, has a high probability of being correct first time, and minimises use of resources and OPEX costs. Early recognition of any issues should facilitate operational changes or timely maintenance of equipment to prevent unnecessary consequential loss. There should not be an operational philosophy of "just restart" after a shutdown or trip without (a) all parties fully understanding the consequences of such an instruction; (b) approval by appropriate expertise; and c) a full understanding of risks and consequences.

Collaboration is possible with full, real-time visualisation of data and field conditions by both the field and remote teams, supported by edge and remote analytics, and better ways to communicate including Virtual Reality (VR) and Augmented Reality (AR) between the two teams. Individuals on either end can miss data or not fully appreciate some condition in the field, so effective collaboration help improve the decision making.

Maintenance of sophisticated process and especially rotating equipment can be very challenging and there are lots of industry examples of incorrect maintenance being done (i.e. inadequately isolated, not really needing to be done, or worse being done so wrong that another worse problem develops). The use of AR by field crews combined with remote monitoring of the ongoing live process and operations can improve safety and help ensure the maintenance is done correctly the first time. There are too many examples of workers removing piping or equipment where live hydrocarbons were possibly exposed to loss of containment. Similarly there are examples of equipment being reassembled incorrectly (i.e. wrong seals, gaskets, inadequate tightening, or wrong materials (CS instead of CRA)).



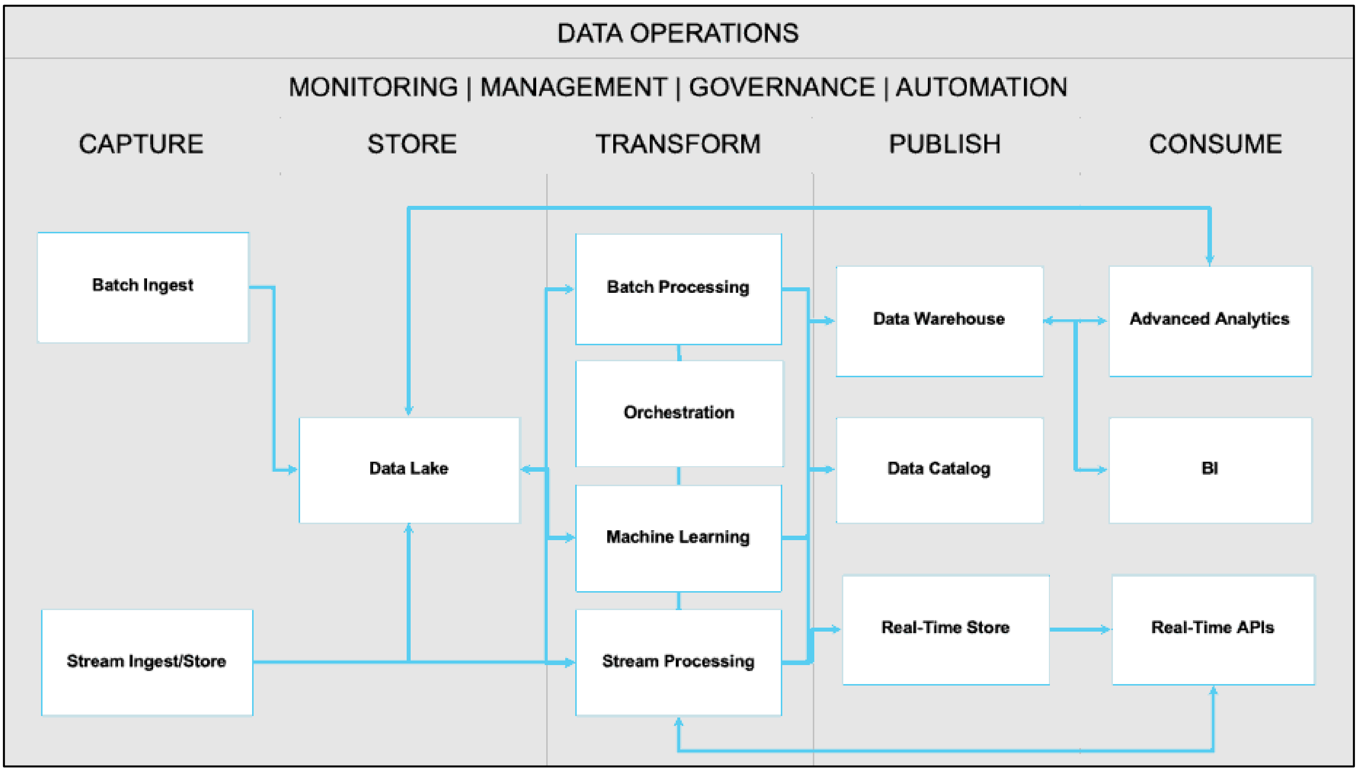


Remote monitoring and diagnostics will facilitate the approach of getting and supporting competent people to do the right thing at the right time (in the right place), a fundamental target of efficiency and cost minimisation. Collaborative Work Environments enable high quality communication, information sharing, and rapid high quality decision making between the field and remote support locations.

18. Big Data

Previous reviews of IoT and communications have helped us understand that significant amounts of data is involved in IIO&P to perform analytics, obtain insights, and help make decisions to capture value, particularly improved safety or operations and maintenance. To do this, a lot of data is needed to be accessible and usable by a wide range of users. It is not data for data's sake – which unfortunately happens frequently – but rather data that is usable for specific purposes. It has to be the right fidelity of data (e.g. frequency sometimes milliseconds, but sometimes minutes) for the necessary analytics. Data has to be cleaned and accurate to eliminate uncertainty in its use and resultant insights.

Data Lakes, Data Warehouses, Data Catalogues, and Data Platforms – are lots of places where this data resides. Data is captured, stored, transformed, published, and finally consumed. The Cloud plays a big part in this story and Cloud Vendors are moving quickly to provide the tools we need. A good taxonomy is the following illustration: (ref. post by Charlie Crocker on *Nuggets*)



Data lakes are usually raw data, purpose still not necessarily determined, used by data scientists, but accessible and easily updated. Data here is or can be transformed with edge and remote analytics performing processing and machine learning. From here the processed data would flow to data warehouses and/or data catalogues. Data warehouses or data catalogues are where this data is more organised particularly after having initial processing done. This allows access for subsequent Advanced Analytics (AA), Business Intelligence (BI), and Application Programming Interfaces (API).

Another useful term is Data Platforms. This is a term to describe all of the above functionalities grouped by a Vendor into a platform for users to use to collect data from various systems, in multiple formats, structured and unstructured, cleaned, and with wide ranges of prior accessibility into an easier space for users to make better use of the data. One of the most important ways to extract value is to contextualise this data. All data has to be linked to specific locations, times, and relevant to other data collected at the same time. In the taxonomy above, a Data Platform essentially combines the functionality of Capture, Store, Transform, and Publish. The Consume functionality operates on the data now aggregated and organised in the Data Platform. Some providers call this the Data Layer with the Consume function called Applications. Underlying the Data Platform is the various data sources themselves which as we have seen before are not limited to structured data from instruments, but can be unstructured visual, written, physical measurements, and conditions in the surrounding physical environment etc. The best kind of Data Platform should combine capabilities to achieve functionalities ranging from dashboards to reports to analytics to 3D representations of the oil and gas facility to captured images – and all linked to users wherever located through automatic and manual connections.

A common challenge to users is whether a bespoke, customised solution is the best way to proceed or whether this Data Platform can be like a “book in a library” (the particular Cloud), able to be removed and placed in another “library” (another Cloud), then able to be read by another set of Application’s AA, BI, and APIs. Appropriate contextualisation with clearly defined rules and procedures should be part of the original solution and not just linked to a particular initial supplier’s bespoke software. Capability to transfer data from one Data Platform to another is desirable from a commercial business perspective, but needs careful initial specification and contracting, plus ongoing integrity of following these requirements to allow “future proofing” and prevent “lock in”. A properly structured and contextualised Data Platform should allow third party users (e.g. oil and gas equipment suppliers with “healthcare” contracts) to access with their APIs and perform their external analytics or check the status of their previously installed edge analytics. Data takes a lot of space and effort to maintain for use – how long to keep data, how much fidelity is needed during routine operations – it is good if there is a capability to collect this data with engineered variability – for example after a period of time of routine operations, more detailed data might be released, but surrounding an event, more precise detailed data should be kept for use to diagnose whatever happened and why. Big Data is a key component for IIO&P.

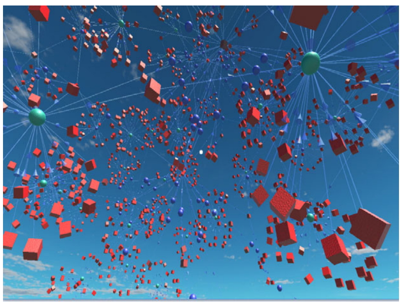
19. Blockchain

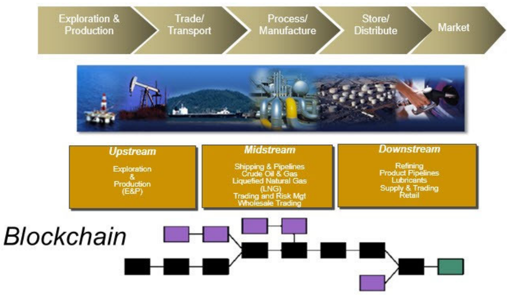
Blockchain is an evocative term – often misunderstood and even misused in the context of IIOI&P. This section is not a deep dive into the subject, but rather should be read in the context of the preceding sections as a general introduction to various topics applicable to IIO&P. For readers with more interest in this subject, please go check out Philip Black's (from *Wood Digital and Technology Group*) articles on the subject on LinkedIn.

Let's start with what Blockchain for IIO&P is not - it is not related to Bitcoin and cryptocurrencies (digital currencies) applications. There is a whole world of Blockchain for these applications, but not in this document.

For IIO&P, Blockchain includes being an encrypted database of agreements. One application is Smart Contracts ("contract that holds both parties accountable by only completing the terms of the agreement once both parties have fulfilled their end of the bargain"). "Blockchain can serve as a bookkeeping platform or a ledger that is incorruptible, enforces transparency, and bypasses censorship." (*Ref. A. Satara, Quora, Forbes)*

Blockchain for IIO&P can be about transformation of supply chain networks and the subsequent connection of suppliers with the long term access, storage, and usage of proprietary data generated from operations using their equipment. Tracking equipment assets is important for integrity during operations and maintenance. Who supplied the equipment or system? Where did the components and subcomponents originate, are they all legitimate with full traceability (as required), and were they correctly installed and maintained as required (to ensure performance and warranties were guaranteed)? If a piece of equipment incorporates IoT devices with software, this technology can ensure they are properly updated as required. For Digital Twins to be effective predictive tools for facilities, the underlying equipment and systems have to be correctly functioning and maintained.





Data residing in Data Platforms (see the previous section about Big Data) needs to be accessible to the respective equipment or system suppliers if they have been contracted to perform remote offline analytics or check the performance of Edge analytics. Equipment and systems need to be checked that they are being operated within best operating integrity limits and then checked to see if there is any degradation of performance due to condition of the equipment or changes due to the fluids being processed. There may be some IP or commercial confidential issues that means this data needs to be restricted to applicable users and using Blockchain can ensure this happens. Monitoring performance can then be linked into Enterprise Asset Management software with appropriate semi-autonomous ordering of spares, inventory replacements, scheduling of service visits, etc.

Payments linked to performance factors could be calculated using Blockchain by tracking "the cost of all aspects of the performance lifecycle" (*Ref. V.Raghothamarao, IHS Markit*) – i.e. capital cost, maintenance cost, operating cost, and efficiency – unique to each piece of equipment or system and the underlying contractual relationship between the parties. Incentives like payment for performance (or corresponding penalties) can be powerful commercial tools to capture more value from production.

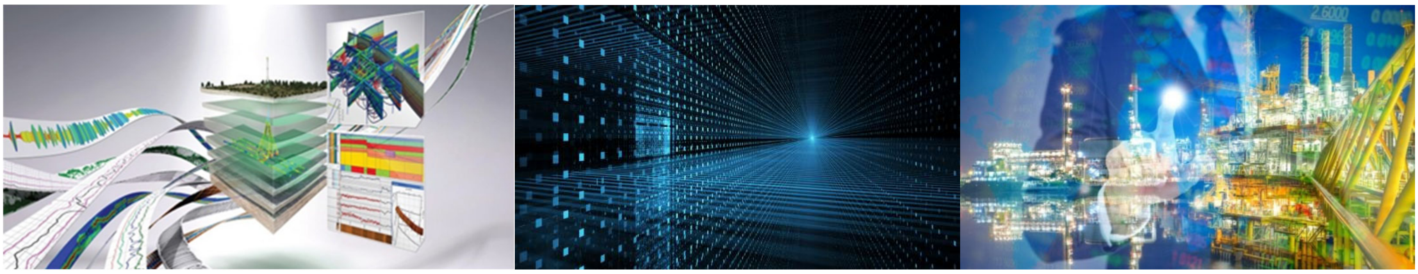
Exchange of information across an oil and gas value chain can be facilitated by distributed ledgers enabling disintermediated access of documentation between various participants of end-to-end value chains. (*Ref. Dr. S. Khoshafian, Pega*) This information can range from engineering to procurement to construction to installation to operating to regulatory. Supply Chain and Logistics are clear beneficiaries of real-time tracking of components and commodities needed for smoother operations and maintenance. Knowing unfiltered, correct information about the dispatch and receipt of these items, where they are located at any given time, and how they can be accessed are important in the streamlining of these processes.

Blockchain can be an important piece of how Integrated Intelligent Operations & Production delivers value but it needs to be carefully interlinked with the other business systems to avoid confusion.

"Blockchain technology is a catalyst for reimagining the way we do business and this consortium represents a collaborative effort to explore the technology's potential and leverage learnings to drive industry adoption" - *Offshore Operators Committee (OOC)*.

20. Data Analytics Strategy for IIO&P

As reviewed previously, Integrated Intelligent Operations and Production (IIO&P) helps us work to achieve more value from our oil and gas industry facilities. We have noted that the correct strategy of work should be to first identify the needed decisions to capture various aspects of value; then the insights needed to help make these decisions; then what analytics could be performed to obtain these insights; and finally what data would be needed to perform these analytics (i.e. type, format, fidelity, cleaned etc.).



Subsurface, operations, and maintenance teams will be most familiar with their technical challenges, so the decisions they need to help obtain more value must be prioritised. Sometimes people have had good intentions aiming for big data analytics project outcomes which were hard to successfully deliver all at once. Multiple smaller projects by agile teams collaborating cross-functionally are easier to deliver and can demonstrate the business case value incrementally to maintain funding and management support. At a recent conference it was stated that 78% of pilot digital transformation efforts were failures and abandoned – this included poor data analytics that collected large amounts of data without necessarily delivering the insights needed.

Agile approaches to developing data analytics and their data platforms will help better connect data to analytics (edge or remote) and onwards to the users. "Enterprises need to undertake integration infrastructure modernisation to effectively exploit digitalisation, mobility, cloud and IoT for driving business growth. There will be less inertia to a shift towards agile approaches to integration and/or cloud-based integration services" (*ref. S. Sharma, Ovum, Computer Weekly*). Getting the right data into the Cloud is one tactic to make it more accessible to the connected users. Historically McKinsey has said that 99% of data streams through control rooms in our oil and gas facilities and is not used effectively. Dashboards can help alert users to some issues, but these reports can be late with not enough detail. Inadequate fidelity of data can also be a problem for successful analytics along with not understanding the related sequence of events without good logs able to be properly analysed.

Once data is properly accessed and used in analytics (which have been previously tested on Digital Twins), the results need to be shared with users. Specific insights need to be presented to the subsurface, operations, or maintenance teams in an actionable format to make the necessary value decisions. For example, specific recommendations about adjusting operational integrity window settings (i.e. valve positions, level settings, and configurations of motors, pumps, and compressors) could be based on results from "what if" operations Digital Twins. Complex reservoirs with multiple production wells (with adjustable production and gas lift chokes) and water injection wells (with adjustable chokes) may need specific adjustments well by well to maximise production recovery from the reservoirs. Integrated asset models can be used to virtually trial various adjustments which are then further validated (or not) in the physical world.

If needed, data scientists would need to be ready to adjust edge and remote analytics as needed (i.e. correlating machine learning results versus physics based models; inputting actual rotating equipment performance curves versus theoretical curves; inputting actual control value performance; further developing outputs to illustrate what is “normal” and what are “deviations from normal”; and importantly for maintenance, what is degradation and how is it recognised in IoT data).

Analytic results are not always obvious to find the insights. There is a difference between observing correlations and understanding what the observations are telling you. Cross-functional agile teams using Digital Twins can test how different decisions might affect production outcomes, and then test whether there is a direct causal link. The strategy needs to be not just spotting correlations, but also finding insights into why they correlate. Our oil & gas industry needs to move from intuition based to evidence based decision making – working backwards from the desired value decisions to the underlying data helps do this with the right analytics.

McKinsey has stated that only 18 percent of companies believe they have the skills necessary to gather and use insights effectively and only 19 percent of companies were confident that their insights-gathering processes were contributing directly to operational effectiveness. This means that if insights derived from analytics are unclear, teams won’t be able to use them to make value decisions. So once data analytics produce results, companies need to ensure they are worked collaboratively to identify the insights – people and culture matters for IIO&P.

21. Types of Data Analytics for IIO&P

Data Analytics is an important way we use the data collected from our oil and gas systems' IoT devices to find insights to help us make value decisions. A key challenge is the fact that significant data may be unstructured (i.e. manufacturing records, maintenance records, production histories, logs, reports, studies, video, audio) - without having had analytics able to process it into more usable format when observed or for better use later (e.g. when looking for correlations). This challenge is discussed below. There are five general types of data analytics:

1. **Descriptive**-"What happened?"
2. **Predictive**-"What will happen?"
3. **Prescriptive**-"What should we do about it?"
4. **Preventative**-"What can we do to prevent it"

(items 1–4) "**Doing things the right way**"

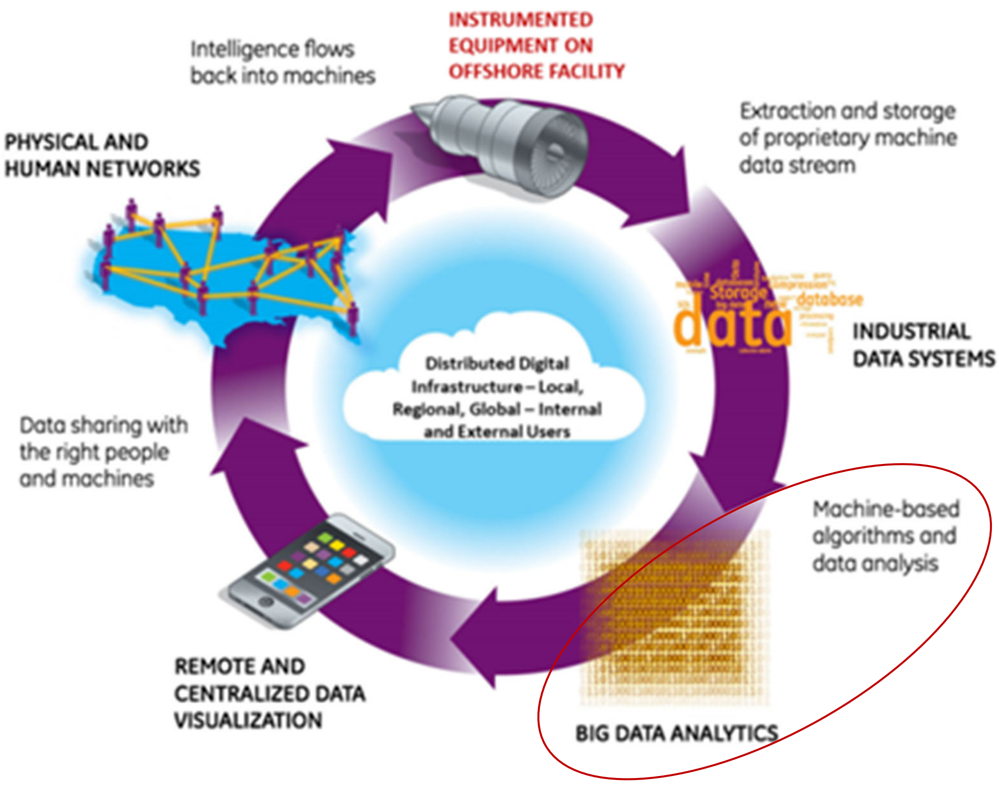
5. **Cognitive**-"What should we be doing to optimize outcomes?" "**Doing the right things**"

Data is able to be analysed in real time (Edge or Stream Analytics) or in deferred (Remote or Offline Analytics) time. Individual IoT data streams can be analysed one at a time or data from groups of different types of IoT devices can be analysed together where there might be relationships able to be used to make predictions of future performance (especially degradations of performance). Structured data like instrument readings might need to be correlated with unstructured data (e.g. FPSO vessel motions where seastates and directionality might affect the ability of a production separator to efficiently separate oil and water).

Real time monitoring of data with Stream Analytics will enhance detection of anomalies or events that require attention from field personnel (due to latency issues) or remote technical personnel (for specialist input or "health care" provider attention). Data analytics on Safety and Environmental Critical Equipment (SECE) and Production Critical Equipment (PCE) should improve predictive maintenance by monitoring degradation of performance – maintenance intervals can expand or contract as required based on actual performance.

Normally unstructured data is able to be better formatted and/or prepared for subsequent use in analytics. Documents can be input into databases with metadata that contain reference data to the component or piece of equipment or larger facility system and made searchable for key data. Vendor manufacturing data is able to be linked with targeted operational integrity data or installation parameters able to be verified against routinely monitored field data. Video, audio, or vibration records can be linked into analytics to establish what is "normal" and what "deviation from normal" is so that analytics monitoring structured IoT data can establish correlations able to be tested for direct causal links. Maintenance records can be used to check frequencies (e.g. too early or too late) with respect to analytically observed degradation. Operational data can be checked (i.e. levels set too closely to limits, valve timings set too quickly with pressure surges, or electrical transients associated with power switching) with respect to analytical reviews of event sequence logs including notifications, alarms, and trips.

Cognitive Analytics would lead to value-adding augmentation of field operators by recommending actions based on experience "learned" from databases (initially guided by expert judgements) combined with cognitive (reasoning based) machine analysis of current data. Cognitive Analytics is facilitated if there is a suitable database of relevant operational data to review and analyse – once operations begin, this database should be rapidly populated and appropriate software can cognitively analyse the data to determine what is “normal”, what is an “anomaly”, and help predict potential failures so that effective asset integrity programs can be implemented to improve availability and reduce unplanned failures. We can determine what is changing (and how) that should not be changing given the particular process conditions (i.e. inlets, outlets) and facility conditions (i.e. motions, environment).

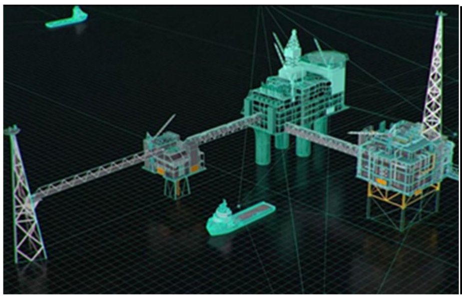


(*Ref. GE*)

Cognitive Analytics also has an important role in feedback to engineering and design processes including specification and selection of equipment and configuration of control systems. The opportunity to make operational integrity windows more robust within normal production variations and feeding back facility constraints to how wells are operated means less production trips and more uptime – which can be significant added value.

22. Artificial Intelligence (AI) / Machine Learning for IIO&P

A lot of progress has been seen in the industrial application of Artificial Intelligence (AI) – what is this exactly and why should we use it in our oil and gas industry? We also hear about Machine Learning – is this different from AI and, if so, how?



Machine Learning (ML) is "the acquisition of knowledge from observing results." One application is to learn from IoT data how to maximize the performance of a single part of a larger system. ML "learns by reasoning through data". ML algorithms remember the data they have processed, so they can apply that learning when next utilised. ML programs are not physics-based they are learning-based (just like people!). In the past, conventional monitoring of IoT data was threshold-based monitoring (i.e. monitoring pump vibrations and temperatures and providing warnings only hours before failure) – but the oil and gas industry wants to have weeks of notice of impending failures to give time for EAM systems to work preparing people, parts, and schedules to make repairs prior to actual failures. Using ML and cognitive analytics, Flowserve reports increasing warning times on monitored pump failures from 12 hours to as much as 5-6 days with false positive rate of less than 2%. ML is only as accurate as the IoT data it receives, so data gaps matter and "tuning" the ML algorithms is needed to keep up with system changes including process fluid changes. ML is looking for "failure signatures" which may be represented by subtle patterns in correlated data across a number of IoT devices, not just one instrument. Aspen Mtell says looking for these failure signatures and scheduling maintenance based on them instead of calendar based maintenance reduced workloads by up to 60%. SparkCognition says cognitive ML algorithms can be deployed to multiple assets and locations and adapt to the unique conditions of each asset, thereby reducing adoption time and cost ("increasing marginal value with decreasing marginal cost" - *Equinor*).

One definition of AI is that "it is how to enable computers so that computers can do things which people can currently do better." Properly developed, AI tools can incorporate cognitive abilities to analyse and process large data sets faster than people using statistical tools, can recognize correlations not necessarily clear to people, and can help automate some system responses. Once deployed, AI should be designed to increase the probability of success at the end of a series of tasks. The goal is to learn from IoT data how to maximize the performance of these tasks (whether this is performance of multiple wells in a reservoir or how a particular process system in a facility is being operated). AI systems require a knowledge base and other supporting systems to be able to make and explain recommendations or decisions. AI "agents" help with gaps in the knowledge databases and interact with human users, but it takes time to build experience and confidence. "If you build an agent today with data and knowledge, you're not going to put it in charge of making decisions tomorrow. Initially, it will be used as a design tool, then it will become a recommendation tool, and then once you build trust, it will be used as a control system." (*Ref. S. Farhadi, Beyond Limits, JPT*)

Similar to other IIO&P topics, AI initiatives face significant cultural and organizational barriers. Leadership cannot assume that AI is something “shiny” to buy and install and get immediate value. Data infrastructure, AI software, data expertise, and simulation models take time and significant organizational changes to produce usable outcomes. Diverse, cross-functional multi-discipline teams (engineering, asset, operations, and maintenance personnel working with data analytics personnel) have to identify and implement changes in workflows to better utilise recommendations from AI systems. McKinsey found that 90% of companies who successfully adopted AI technologies had actually spend more than half of their analytics budget on workflow redesign, communications, and training. A difficult challenge is developing the trust to follow AI recommendations at working levels instead of relying on top-down conventional hierarchies of decision making. Agile teams will also enable iterations of solutions quickly (there will be failures) so that the learning curve progresses more rapidly to achieve more valuable outcomes. AI should not be viewed as something that replaces or eliminates people, but rather understanding that AI can enhance and optimise the connection of field and remote technical teams with the best possible performance of their underlying assets (whether subsurface reservoirs or complex production facilities).

“The end game is not automation for the sake of technology but finding the ideal blend of human and machine capabilities in every function, and using the resulting productivity gains to redeploy employees to tasks that can improve business results” (*Ref. EY*)

23. Why Oil & Gas needs Application Programming Interfaces (API's)

Application Programming Interfaces (API's) are essential tools to facilitate the extraction of IoT Data from our Cloud based Data Platforms in order to perform remote or offline Data Analytics or to review the results of Edge Analytics already performed with results stored in the Data Platform. (A more familiar API to the oil and gas industry is the American Petroleum Institute but that is not what digital transformation API's are all about!)

API's are like software keys to enable the access and unlocking of data from where we have collected and stored it. When raw data is accessed from our IoT devices, data ingestion API's help organize it on our Data Platforms where it is contextualised and made ready for use. Data can remain fairly basic, but there can also be internal processing API's within the Data Platform processing the data, cleaning it, and potentially helping to identify gaps or errors. Then data consumption API's are available to access this contextualised and prepared data to perform various functions like dashboards, machine learning, visualization, and digital twins like dynamic process simulations.

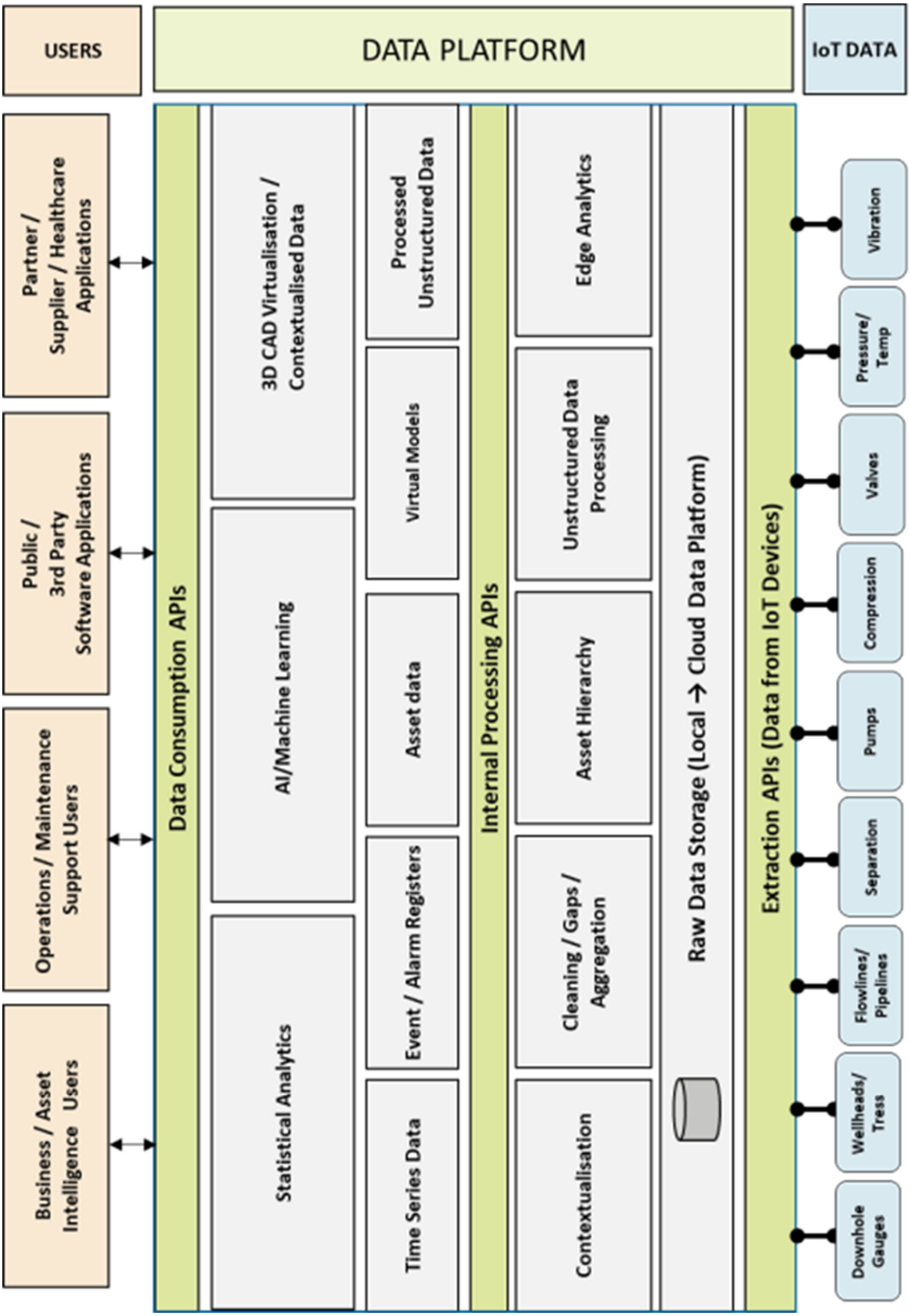
Sharing of data, insights, and decisions happens with users located anywhere – whether they are in a remote asset team or contractors delivering "healthcare" (operations integrity and/or maintenance related) responsibilities for specific equipment and systems. Collaborative working is critical for IIO&P as we have noted before.

Inside the Cloud Data Platform there should be a central API management platform, which can act as a single source of truth for developers (internal and external) building the applications to access the data, process the data, and supporting the use of monitoring tools. Multiple internal and external users need to be able to access data, run their software or analytics, and update the databases.

Blockchain can be used to restrict the API access rights of external parties to specific equipment, systems, or types of data they are authorised to access, process, and feed insights and recommended decisions back to the operations and maintenance teams.

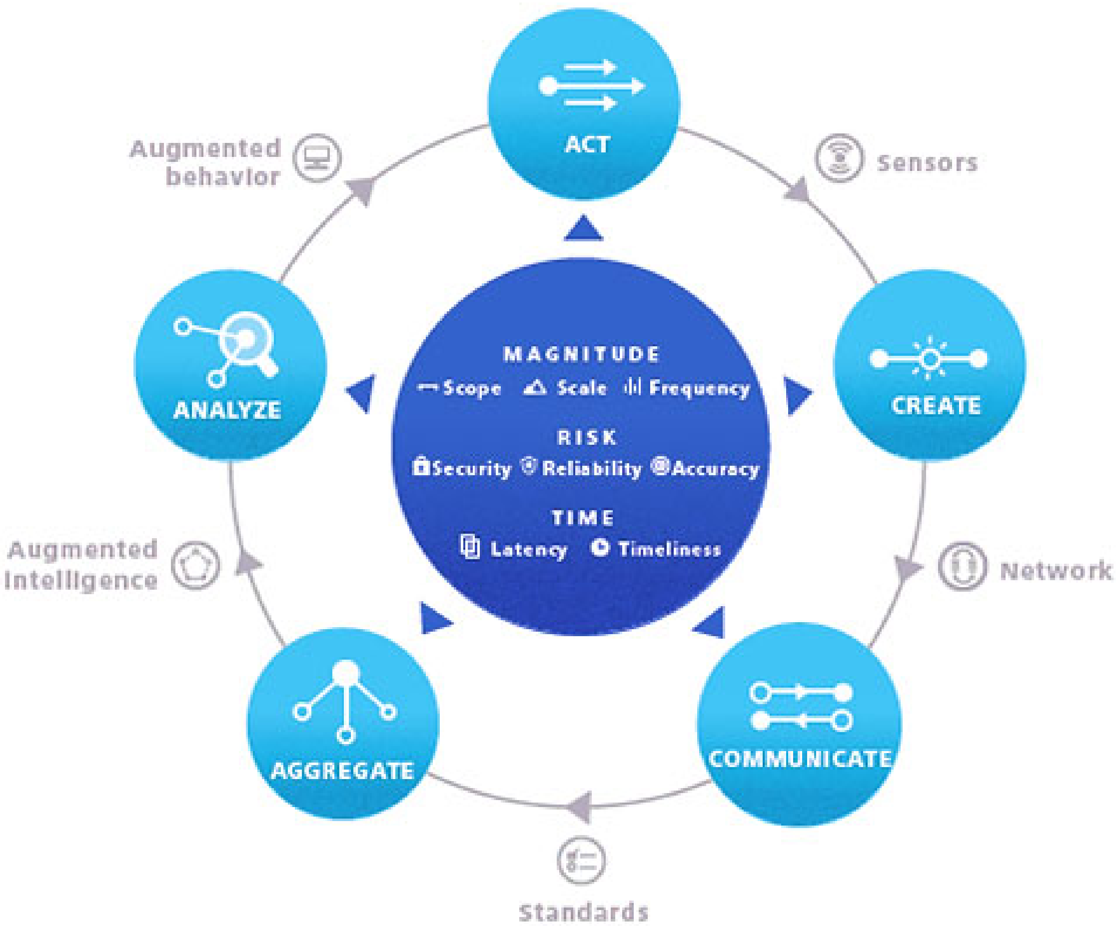
API's allow the underlying Data Platform to remain relatively untouched as users work towards better use and exposure of the data with increasingly sophisticated data analytics, machine learning, and artificial intelligence. Deloitte states that API's support "interoperability and design modularity". API's open the data up to a wide range of users ("consumers") and user devices – using layers of API's accessing data on enterprise systems from SaaS (software as a service) to mainframes to Cloud apps to applications to FTP to databases to Web services to files. This is a powerful logical architecture to help oil and gas users to find insights and capture value.

The next page shows how these API's function within the context of a Data Platform.


USERS
DATA PLATFORM
IoT DATA
Partner / Supplier / Healthcare Applications
Public / 3rd Party Software Applications
Operations / Maintenance Support Users
Business / Asset Intelligence Users
Data Consumption APIs
3D CAD Virtualisation / Contextualised Data
AI/Machine Learning
Statistical Analytics
Processed Unstructured Data
Virtual Models
Asset data
Event / Alarm Registers
Time Series Data
Internal Processing APIs
Edge Analytics
Unstructured Data Processing
Asset Hierarchy
Cleaning / Gaps / Aggregation
Contextualisation
Raw Data Storage (Local → Cloud Data Platform)
Extraction APIs (Data from IoT Devices)
Vibration
Pressure/ Temp
Valves
Compression
Pumps
Separation
Flowlines/ Pipelines
Wellheads/ Tress
Downhole Gauges

24. Data Analytics in IIO & P

As discussed previously, modern oil and gas facilities with large numbers of IoT devices have the potential to capture significant amounts of time-series data. This data may be too much to move in real time through the facility SCADA systems (polled architectures on serial connections collected in minutes). "Facilities systems with 50 sensors at a 100 hertz sampling rate require 2.8 Mbps bandwidth for standard JavaScript Object Notation (JSON) to stream data. Fewer sensors, but at a higher fidelity required for asset condition monitoring, say 20 sensors at a 1,000 hertz sampling rate would require 11.4 Mbps JSON." (*Ref. D. Thompson-Beckhoff Automation*) Most oil and gas facilities contain orders of magnitude more sensors, so all data cannot be collected at high fidelity all the time. We just do not have enough bandwidth and do not need to store all data all the time. Data can be collected alongside normal control systems through application gateways (polling IoT devices in seconds) and processed within the remote facility instead of only being collected and sent to the Cloud. Certain data analytics can be performed inside the equipment PLC's or IPC's. We do not need to send full time-series data in high fidelity applications in real time through communication systems. Doing some pre-processing on the Edge, eliminating a lot of "all OK" type data from real-time streaming, data compression, and sending more limited data will be more feasible. When Edge analytics detect abnormalities or "failure signature" indications, higher fidelity data streams can be upgraded to real time for action by remote users and/or offline analytics.



(*Ref. Deloitte "Connected barrels"*)

Consider the case of rotating equipment onboard a remote oil and gas facility. Normal safety and control instrumentation would be connected from this equipment into the central control room. Operational integrity limits on individual instrument readings would be monitored against specified values. Experience has shown us that individual IoT devices can help show when something is being operated incorrectly or when something is in the final stages of failing, but there may not be enough notice of these issues. Progressive degradation of equipment can happen without being noticed without some form of analytics. We have two ways of trying to overcome this situation: Edge analytics or remote analytics – both of which are processes to achieve Augmented Intelligence. The insights achieved could lead to Augmented Behaviour which is the actions we might take to capture the value identified (*Ref. Deloitte*).

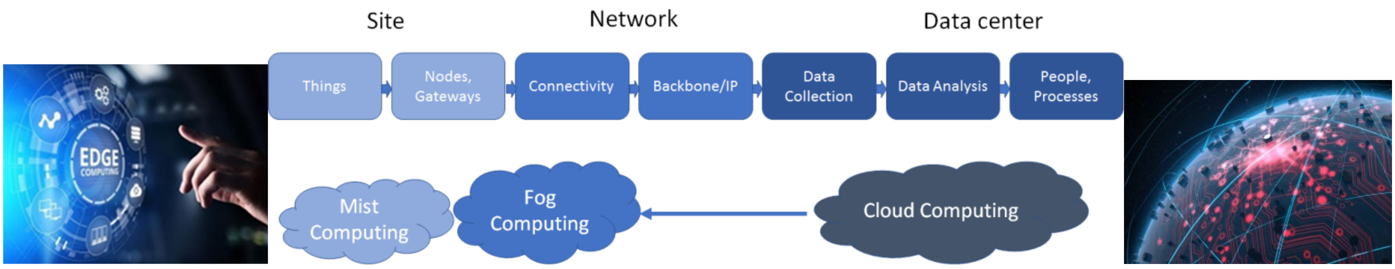
Edge analytics can be performed on equipment inside local PLC devices. If mixtures of wired and wireless data collection systems are used within the facility, this processing could also occur in Industrial PC's (IPC's) inside a nearby LER or E-House or even in the Control Room. Individual instruments would show important data, but failure signatures might be revealed by considering several instruments or systems together. Adjacent IoT devices (upstream or downstream of this rotating equipment) may need to be considered to be able to reveal an emerging issue in enough time to prevent more serious degradation including unplanned shutdowns. Converting raw data is an important aspect of Edge analytics – for example: (1) raw accelerometer data can be converted to frequency domain locally which is more usable remotely; and (2) data can be processed deterministically (using pre-processing algorithms to send values only upon a change) or stochastically (sending statistical information like averages, trends, or cycles). As Edge analytics utilise more powerful processors (and storage) they can populate and utilise Machine Learning databases and simplified AI to facilitate increased automation.

Processing of raw data for these analytical purposes can be done in Edge devices, but some types of analytics especially those looking at long time-series data across a wider system level may require to be done remotely and therefore offline. Remote analytics are familiar to many oil and gas industry participants and range from statistical analyses through large scale Machine Learning up to sophisticated Artificial Intelligence. Some of these analytics may require more specialist users not present in field operational teams. As operational experience is gained and as operational databases are grown, analytics need to be flexible to "learn" and be modified by data scientists to keep up with the characteristics of a facility as it matures (ages) and as production fluids might change (differing rates, compositions, pressures, etc.). Analytics can be purely statistical, based on physics, or based on Machine Learning. AI will help bridge data gaps, serve as data agents, and eventually help automate some of the integrity and value responses in a similar way safety systems do now.

Whether it is Edge analytics performed in streaming time or remote analytics performed offline, results and insights have to be captured in the Data Platform as we read in the last section. Users will utilise API's to access data, review and modify edge analytics as needed, and perform remote analytics to identify insights and help the field and remote teams to make decisions to capture the desired value. It is a collaborative effort as always.

25. "Cloud / Fog / Mist" in the Oil & Gas IoT Data World

Most people have heard of the term "the Cloud" – and it has featured prominently in earlier sections, especially when talking about our need for a Data Platform accessible to users everywhere and able to be loaded with raw and processed data. But there are also terms like "Fog" and "Mist" that are used. What are these and how do they relate to "the Cloud"?



(Ref. Capgemini)

First, what is "the Cloud"? Microsoft defines this as "a term used to describe a global network of servers with various functionalities...The Cloud is not a single physical entity, but instead is a network of remote servers which are linked and operate together...These servers are designed to either store and manage data, run applications, and/or deliver content or a service…There are public Clouds that share resources and offer services to anybody over the Internet; private Clouds that aren't shared and offer services over private internal networks typically hosted on premises; and hybrid Clouds that share services between public and private Clouds depending on their purpose." Remote field facilities can be connected into the Cloud in various ways as mentioned in previous sections ranging from copper to fibre to satellite. Latency (time lag) can vary from minutes to days, suitable for human-machine interfaces (HMI), offline analytics, and business intelligence (including enterprise operations). The Cloud is a likely eventual home for most critical data for long-term use and records. The database of contextual information from design to operations would typically reside here to be accessed by multiple users.

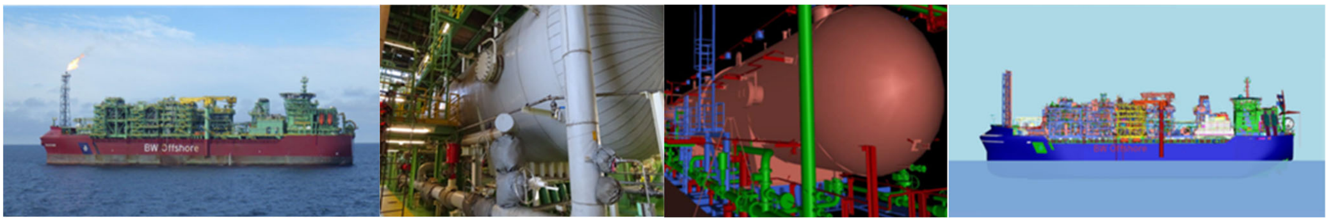
For the various communication pathways, collecting data, running analytics, or performing applications only in the Cloud may result in latency, bandwidth, reliability, or security issues. Fortunately we have additional technologies in the Edge to help us as follows. The term "Fog" (coined by Cisco) has been used to help characterise what are nominally some Cloud computational capabilities extended closer to the Edge ("dense computational architectures at the network's edge"), often in the local network (maybe even inside the field Control Room). Servers can be IPC's gathering data, processing it here, running certain analytics, and uploading appropriate data to the Cloud. An obvious benefit is the proximity meaning that latency is significantly reduced with virtually unlimited bandwidth associated with hard wired (copper or fibre) connections for high fidelity data sources. Wireless data pathways are also available to facilitate data transmission where required. Latency can vary from seconds to sub-minutes, suitable for human-machine interfaces (HMI) and machine-to-machine interfaces (M2M). Interestingly, Fog devices could actually help some IoT devices be less "smart" than they need to be in some other applications because the aggregation of data at the Fog level in IPC's can have much more powerful capabilities whilst still having the Edge benefits. A risk of Fog devices which may need to be considered is the fact that additional links from IoT devices to Fog devices to the Cloud mean more potential points of network failure. Kinetic mesh networks may be one way to ensure Fog devices remain connected even if some links fail.

The lowest portion of the Edge uses the term “Mist” which is where computational ability can be present in the equipment or skids, often in the IoT devices themselves, otherwise in local gateways (maybe inside the LER or E House). Latency can vary from milliseconds to sub-seconds suitable for M2M interfaces, especially where time is critical to avoid consequences. Microchips or microcontrollers can be used to do some of this computing, but they can have some constraints on compatibility with other devices and operating systems so their applications may be limited. Local pre-processing of data can save power (less power required to process than to store data), reduce bandwidth for data transfer requirements, and eliminate some latency (time delay) concerns. IBM uses a good analogy of a self-driving car with sensors to check its surroundings – if this car was driving at 50kph, getting an environment analysis after 2 seconds would be pointless since the car would be 27 meters farther along (hitting something?). Mist computing can complement Fog computing which complements Cloud computing. They do not all function at the same time in the same way, but they can work together and help each other.

There is a US National Institute of Standards and Technology (NIST) recommendation document that provides additional definition of these terms (https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.500-325.pdf).

26. Digital Twins in the Oil & Gas IIO&P World

"Digital Twin" is another familiar term in preceding sections. There can be many types of Digital Twins, so it is important to get the terminology correct. One definition is that "A Digital Twin is a virtual representation of an asset, used from early design through building and operation, maintained and easily accessible throughout its lifecycle" (ref. DNV). Digital Twins are used in the design and operation of oil & gas facilities to improve safety, reliability, operability, and maintainability.



Three main types of Digital Twins can be identified: (1) Data; (2) Process; and (3) Physical:

- A Data Digital Twin is a collection of engineering, design, manufacturing, construction, and test data ranging from 3D CAD computer models to manufacturing drawings to instructional videos. Mostly unstructured data from early design engineering to increasingly structured data from procurement and pre-commissioning / commissioning and start-up is aggregated into this Digital Twin. It has the ability to gather drawings, images, and videos of the design and procurement, ranging from assembly drawings to "how to" instruction videos for testing, operations, and especially maintenance. Operations and maintenance personnel can be "trained" and "practice" planned field work, to the extent of participating in virtual reality training exercises or being supported via augmented reality for actual field maintenance. It is important to contextualise the unstructured data (e.g. linked to equipment or IoT devices in interactive 3D CAD models) to allow it to be "searched" or linked to field situations. Field workers need to be confident that they are prepared with adequate knowledge, tools, spare parts, and the necessary isolations before they ever leave the safety of the control room or living quarters.
- A Process Digital Twin consists of the following elements consolidated in a Dynamic Simulation Process Model: (a) all the process layout and streams conditions (Compositions, Pressure, Temperature, Flow, etc.); (b) all the equipment geometric data (dimensions, elevation, tray sizing, sensor location, etc.); (c) all equipment manufacturer performance data (pump and compressor curves, heat exchanger data, etc.); (d) all actuated valves (valve pressure drop, sizing, timings, etc.); and (e) all instrumentation (control loops, PID algorithms, instrument ranges, tuning constants, etc.) (*ref. J. Ferrer-Inprocess*). Initial dynamic simulation models are used to perform process and flow assurance analyses. Control emulations are then added to design and check functionality of process safety and control systems. An Operational Training Simulator (OTS) model is able to be derived to allow training of operational personnel. Once vendor data is incorporated, the Digital Twin can be used to help improve field operations and maintenance.
- A Physical Digital Twin is used for Structural and Naval Architecture analyses: (a) a floating offshore facility is subject to metocean (wind, wave, and current) conditions which cause the facility to experience hydrodynamic motions, forces, stresses, and fatigue; (b) theoretical

metocean seastates can be simulated for initial design purposes; (c) actual offshore motions are able to be measured in real time and then input into a floating analysis package which is able to predict stresses/strains and fatigue behaviour so that optimised inspection activities can be planned to check the floating facility throughout its life for integrity.

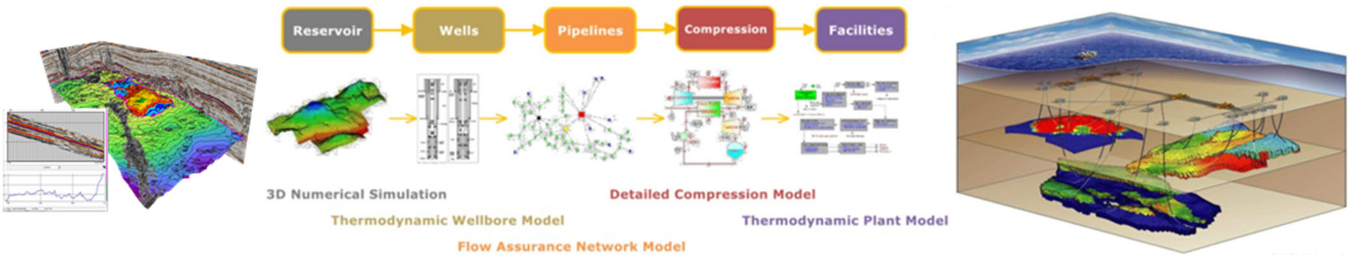
Digital Twin algorithms need to be properly prepared (*ref. J. Morelos-Lloyds Register*). Just having a Digital Twin is not enough – (1) high quality data combined with poor algorithms will lead to incorrect results; (2) poor quality data combined with good algorithms will also lead to incorrect results; (3) high quality data with good algorithms will lead to results which may or may not be correct – the results need to be checked somehow. We have to check the "correctness" of results with collaborative efforts by data scientists working with experienced technical teams to ensure fact based outcomes. Consistency is also important to be able to be demonstrated so that systematic confidence exists. With quality data, the Digital Twin would be ready to help identify insights and capture value by improving operational settings or identifying equipment degradation prior to any failures.

Subsurface value can be enhanced with dynamic simulation models linking the subsurface reservoir to the wells to the subsea architecture to the risers to the floating process facility – often called Integrated Asset Models, they can deliver 6-8% more recovery (earlier ramp-up, longer plateaus, and slower decline in the production). A good incentive to collaboratively engage Subsurface, Subsea, and Surface Facilities teams, models, and data – Digital Twins need to link across the entire development and they need to start early.

27. Integrated Production Management Systems for Oil & Gas

The topic is quite familiar to our Subsurface Teams but the rest of our oil and gas teams need to understand how this tool can be interlinked into other digital transformation tools to better deliver Integrated Intelligent Operations & Production. An Integrated Production Management System (IPMS) can also be known by either Integrated Asset Model (IAM) or Integrated Production Model (IPM). They are a form of Digital Twins, simulating physical processes, looking for insights and value.

Typically oil & gas companies segregate development teams and disciplines – Subsurface teams often get their work done and then, after production starts, they obtain field data and work to optimise well production from the reservoirs. Subsea Facilities teams similarly perform their work modelling from the wellheads to the surface facilities and later obtain field data to check how they might adjust the surface tree chokes or surface facility arrival control valves to improve flow assurance in the pipelines. Finally, Surface Facilities teams work assuming target arrival pressures and flow characteristics and then later obtain field data to see how the topsides facilities might be adjusted for better process performance. Sometimes these teams are physically located apart even when on the same asset team. These practices do not reliably ensure optimised production and value. In previous sections it was mentioned that some oil and gas companies can get 6 8% more subsurface resource value from their reservoir assets – how do they do this? They do things differently…



The first way is to better connect the various development teams and disciplines. Co-locating teams is important to ensure frequent cooperation on better integrated models, identifying insights and ensuring they are evidence based, making decisions, and capturing more value. The teams should collaboratively model the subsurface wells with surface facilities using Integrated Asset Models. Two challenges: first, simplified subsurface well models can be challenged to properly model well performances of multiple reservoirs in the same development with different pressures and reservoir fluids; second, the surface facilities can be complicated if process facilities are involved. Examples of fields exist where the subsurface was "optimised" (with standalone models) but the surface facilities had issues (i.e. slugging in subsea pipelines and risers or hydrodynamic slugging (gas fluctuations) in topside process facilities) that precluded overall optimisation. More sophisticated dynamic simulation models are needed in these scenarios. A complex reservoir might have many variables to be adjusted to optimise production (i.e. production well surface chokes; production well gas lift chokes; water injection well surface chokes; and gas injection well surface chokes). Multiple stacked reservoirs with a range of downhole pressures have to be carefully combined with surface choke settings to avoid constraining the production of lower pressure reservoirs. Fortunately there are software systems to more accurately simulate these kinds of scenarios, but it can still be difficult to simulate dynamically all at once. Some systems model the subsea pipelines, risers, and surface process systems together, but the challenge is to also bring in the subsurface models. Different software solutions have methods to combine or link the models iteratively.

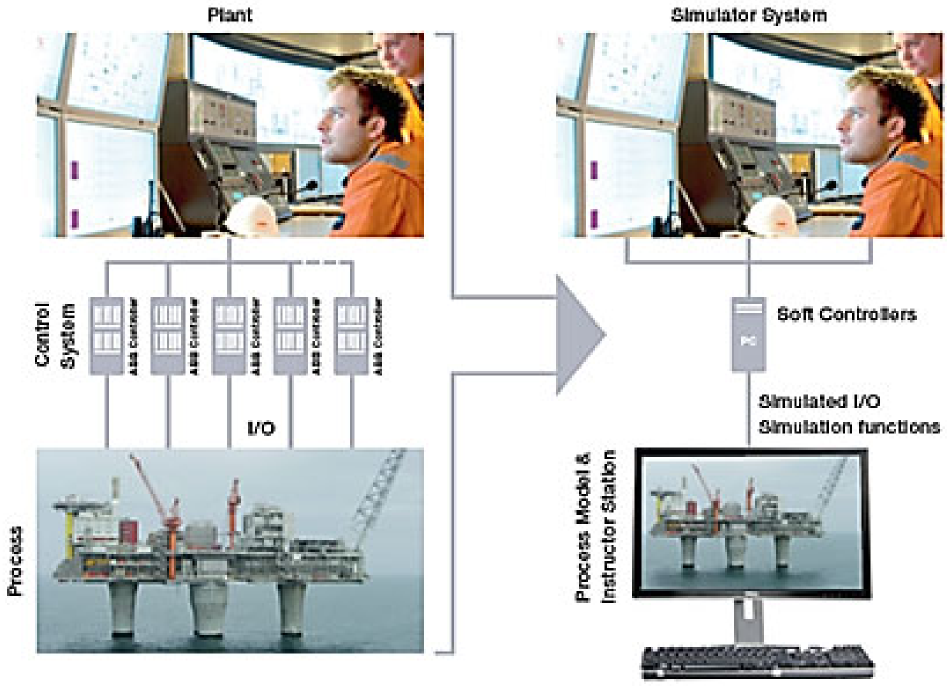
Transient flow conditions present some of the most challenging scenarios to dynamically model, so a series of analyses may be required. The key is to be evaluating the combined system as much as possible and look to optimise it holistically. This may mean trade-offs with apparently less optimal subsurface decisions, but when you consider production interruptions from slugging or difficulties in well start-ups, the overall benefits can be realised. Making adjustments to the various chokes can effectively “tune” a combination of wells and reservoirs to produce higher combined rates sooner, have longer plateaus, and slower decline curves.

Boundary conditions are one of the most significant challenges of discrete models – a subsurface model may not adequately consider the impact of subsea infrastructure configurations (i.e. how wells are manifolded together, how wells might be placed into different flowlines to balance flow characteristics, or how wells might be staged and sequenced to facilitate start-ups – all of which affect flow in the wells themselves). A topsides model might experience flow issues when simulated on its own that don’t consider the behaviour impact of the connected risers and pipelines and even the wells. Boundaries cannot be neglected in transient or dynamic flow conditions. Integrated intelligent operations and production means identifying how properly combined dynamic simulation models may better identify ways to optimise production, making start-ups easier, and damping adverse flow behaviour that may impact these start-ups and challenge the ability to maintain stable control.

28. Operational Training Simulators (OTS) for Oil & Gas

Previously it was noted that dynamic simulation models of facilities with added control systems and HMI emulation could be used as Operational Training Simulators (OTS). Oil & gas facilities may be complex systems of process equipment including separators, control valves, level controllers, rotating equipment (i.e. pumps, compressors, and power generation), heat exchangers, etc. Experience from event log monitoring has shown that a range of operator responses are possible from the same process situations – and not all responses are optimal, some of which actually have led to faults and interruptions. A survey of North Sea gas compressor trips found that ~40% were due to suboptimal operator responses to normal process situations. The results of performance monitoring of a fleet of ~30 no. ships found that a couple of these vessels had significantly worse fuel efficiency due to suboptimal engine operations by their crews. Surveys of North Sea facilities found that not all crews were trained on a range of operational scenarios and sometimes not even adequately trained on all facilities (e.g. trained on topsides systems but not trained on linked subsea systems). Nameplate operating scenarios are fine, but crews need to be trained on real world variable scenarios (i.e. min/max/ramp-ups/turndowns). During training for these kinds of scenarios, issues or gaps in the theoretical design of facilities sometimes needed to be rectified prior to field operations. There is an unenviable record of many oil & gas facilities where the operating control and safety systems were tweaked and modified during final commissioning and start-up with associated delays of weeks and months in ramping-up production and maintaining steady state production on the nominal production plateau. Significant lost value!

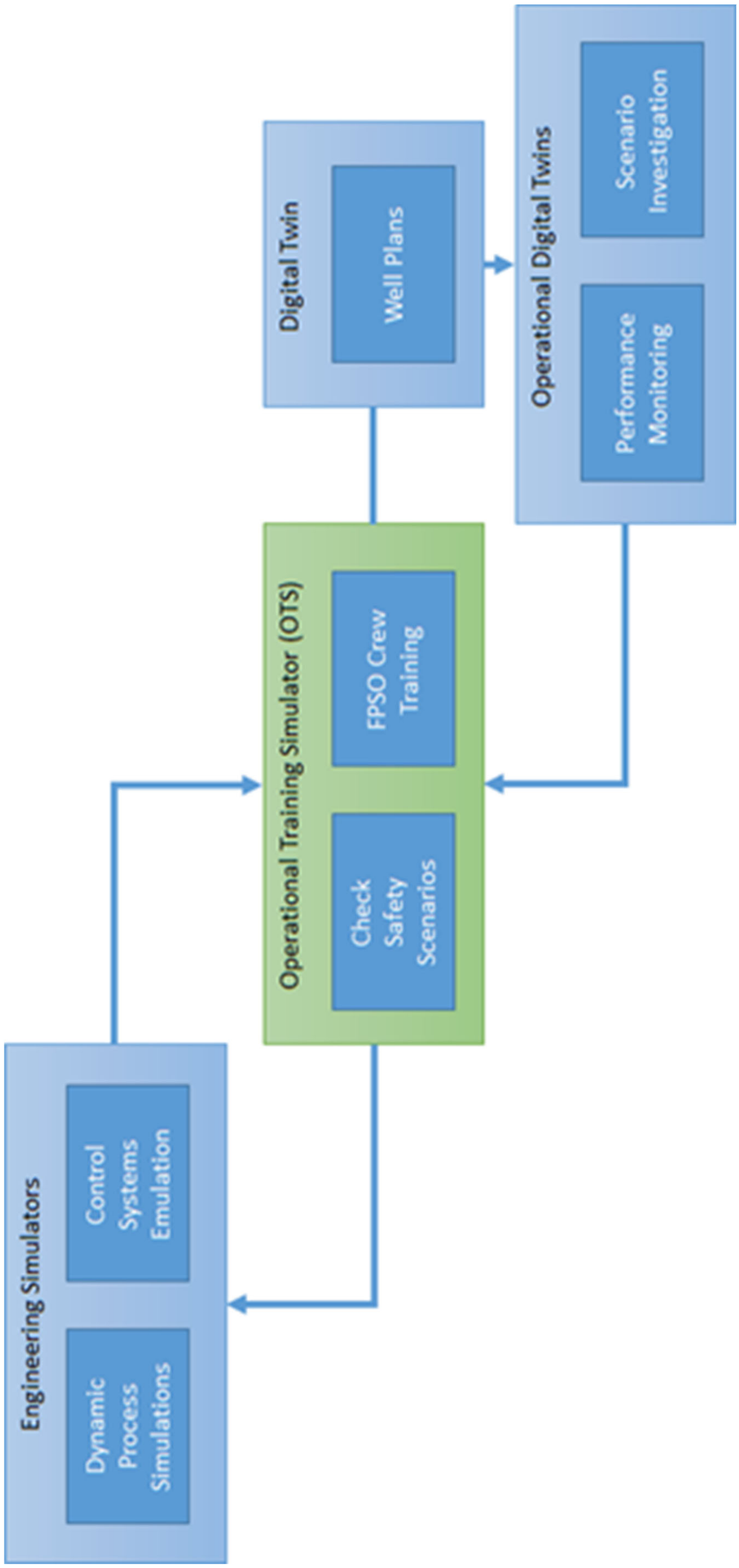
A solution that has been demonstrated successfully on a number of oil & gas facilities is to use an OTS to train the operating crews on the particular facilities before they even mobilise to the field. The best time to train these crews is actually during Detailed Design of the facilities (including the process safety and control systems). That way, the experienced Operations crews can help design engineers resolve any issues discovered. Once “trained”, the Operations crews can mobilise to the shipyard or fabrication yard to assist with facilities’ walk-downs, pressure and integrity testing, loop tests, pre commissioning and commissioning. Having crews who will eventually be responsible for taking over these facilities is a good way to ensure these pre-operations activities are properly performed. And the experience builds confidence and familiarity with the facility in the operating crew.



Some of the functionalities possible with such an OTS could include: (1) run faster or slower, in steps, or even “freeze” the simulated (or actual recorded) process and control actions and responses; (2) test various initial process conditions from cold start to ramp-up to steady state to varying process fluid inputs to turndowns to process upsets; (3) check “what-if” scenarios for responses and actions to maintain stability of the process; (4) train and test operating crews for simulated event and alarm scenarios; (5) simulate loss of signal or functionality of various IoT devices to check performance of virtual instruments and operator responses; and (6) check facility and operator capabilities to any other simulated changing field conditions. The feedback loops of all the lessons learned from this training is typically invaluable.

A good example of such a system was illustrated in a technical article by Inprocess and Yinson engineers for an African FPSO (*Ref. “FPSO Lifecycle modelling adds benefits to development offshore West Africa”, World Oil, November 2017*). Yinson’s feedback from field start-up operations indicated the process was able to be started up in automatic mode and run smoothly for initial operations in spite of challenging well behaviour (e.g. slugging). Dynamic simulation studies of complex gas compression and water injection operations predicted transient behaviour where the control system logic responses and procedures needed to be modified by operations teams to ensure smooth operations. All this was done prior to field operations thereby saving significant potential production interruptions. Inprocess further simulated the field operator devices and local control panels to perform procedures and scenarios to deliver better OTS training.

Proper Asset Integrity Management requires operator competency which can be predictably delivered by proper training prior to field operations and training updates during operations as field conditions evolve (including continuous improvement). The use of an OTS is a cost effective way to deliver this training and at the same time effectively test the underlying design and equipment systems response to real world scenarios. This is part of the path to successful IIO&P.

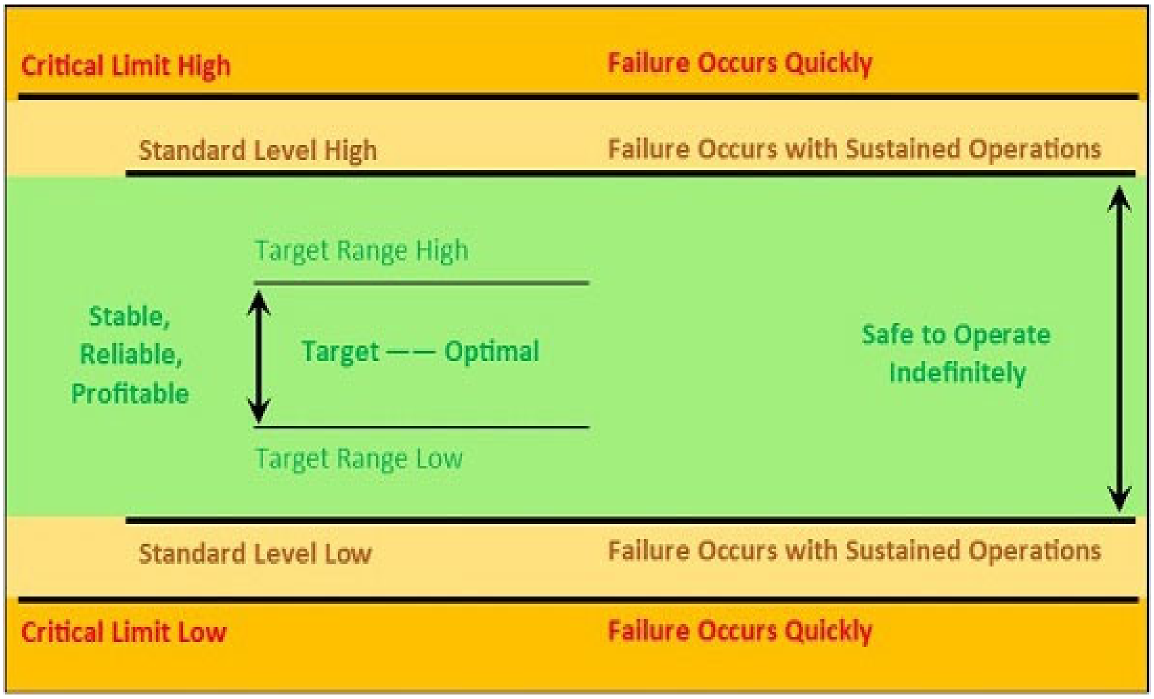


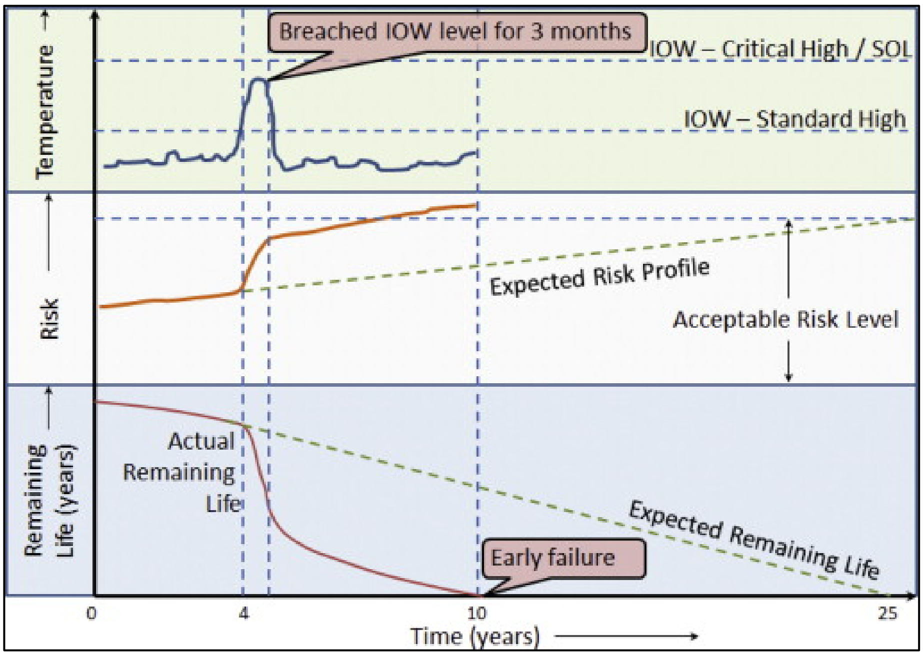
Engineering Simulators
Dynamic Process Simulations
Control Systems Emulation
Operational Training Simulator (OTS)
Check Safety Scenarios
FPSO Crew Training
Digital Twin
Well Plans
Operational Digital Twins
Performance Monitoring
Scenario Investigation

29. Integrity Operating Windows for Oil & Gas Facilities

API RP 584 document on Integrity Operating Windows (IOW) provides good advice of how to design and operate our oil & gas facilities to help deliver Integrated Intelligent Operations and Production. IOW are defined as a set of "limits for process variables (parameters) that can affect the integrity of the equipment if the process operation deviates from the established limits for a predetermined amount of time". IOW need to be determined at the start of a project by defining design and operating conditions; defining potential damage mechanisms (e.g. how equipment or systems might degrade); listing all process variables that might affect each damage mechanism identified (i.e. excessive pressure fluctuations/surges, inadequate cooling/high temperatures, unexpected flow rates, compositional variations especially contaminants, deposition of wax/asphaltenes/scaling); setting operating limits to avoid unacceptable damage rates; then determining levels within these limits for informational/standard/critical operations including considering necessary actions and response times if these limits were exceeded.

IOW should be theoretically considered in the engineering design (when selecting, sizing and specifying equipment with respect to desired operating conditions); checked and calibrated with suppliers (to ensure the actual equipment is aligned with theoretical expectations); tested in the pre-commissioning and commissioning phases (to ensure installation and operation guidelines are functional and deliver the expected nominal operating conditions); and monitored during operations (to see if anything else has changed since the original design). At this point, Digital Transformation Analytics should be able to take over and monitor ongoing performance IOW conditions.





Ref. "Utilizing Integrity Operating Windows for enhanced plant reliability & safety", V. Lagad and V. Zaman – Lloyds Register, Journal of Loss Prevention in the Process Industries, May 2015

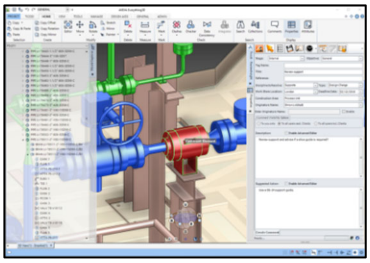
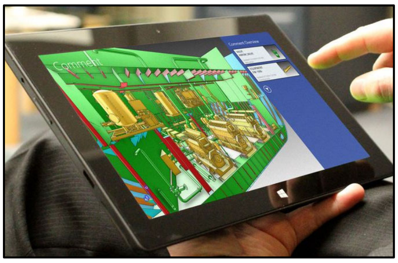
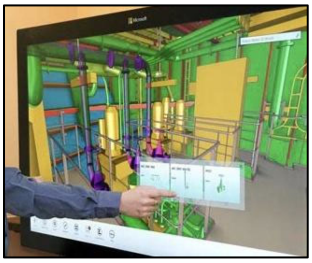
IOW's can apply to individual instrument readings (~"2 dimensional"); to edge processed groups of instruments readings (~"3 dimensional"); or to some form of analytics processed data about a production system (if the analytic was looking at limit trends over time this could be ~"4 dimensional"). These three types of IOW's could also be from virtual readings in a Digital Twin model responsible for monitoring real time process conditions.

Operations teams have various ways of identifying when conditions of one of these types of windows reach a limit where increased risk is being experienced and/or remaining service life is being adversely affected. Normal operations dashboards can receive and notify relevant field or remote personnel in some manner. Alarms can trip and produce a range of outcomes from simple notifications (likely informational limits) to actual changes to equipment settings including shutdowns (likely for critical limits) until the cause can be diagnosed and rectified. A previous section described "failure signatures" which is another way to identify when a series of data or processed data is indicating increased risk of failure.

A range of analytics from dashboards (simple descriptive analytics) to Digital Twins (as described above) can initiate more detailed higher fidelity analytics (predictive, prescriptive, and even cognitive (Machine Learning and Artificial Intelligence)). As described previously, some of these high fidelity data streams could be so bandwidth intensive that Edge computing devices would be needed to pre-process the data and even to perform some of these analytics to help notify the field and remote personnel that IOW were being exceeded and degradation was occurring unless immediate remedial action was taken to mitigate the risks. With enough confidence in properly developed and checked AI analytics, automation agents could be used to change operational settings and/or initiate more serious action like shutdowns depending on the risks. The key is to provide much better information to the field and remote personnel so that proactive measures can be taken instead of just waiting for equipment and systems to fail. API RP 584 reminds us that asset integrity programs generally have assumed inspection and replacement intervals on the basis of what is known about equipment degradation from generic industry experience – but in some facilities it can mean overly frequent inspection and replacement of certain equipment (unnecessary cost) and lack of proper monitoring of IOW to maintain better control over process conditions (causing unexpected failures).

30. Virtual Reality (VR)

Virtual Reality (VR) is a powerful tool that is evident everywhere today in the media and social worlds. It also has a beneficial role in the technical world of oil and gas facilities to help deliver integrated intelligent operations and production. In previous sections Data Digital Twins were described. This kind of Digital Twin was described as being a 3D CAD model of a facility with contextually linked data underlying the virtual representations of equipment and systems inside the model. Users, whether they are engineers in early project phases or operations and maintenance teams in later production phases, can enter the 3D CAD model in a Virtual Reality mode and access significant amounts of contextual data through hyperlinks. Whether it is on a computer screen, a wall mounted touchscreen video panel, or using VR headsets, users can move through the virtual model of the physical facility and access or input the data they are working with. These pictures are from *Aveva* 3D CAD models being used this way:


Data can range from unstructured engineering design data, to supplier manufacturing and testing data, to construction drawings, and to process and test data from pre-commissioning and commissioning. During production operations, real time process data can be available in a VR system to check integrity operating windows or help diagnose potential performance degradation of equipment systems. For maintenance, technicians could view training videos and instructions in VR and then using a VR headset and gloves "enter" the 3D CAD model to simulate how tools and spares could be manipulated to remove and replace parts using simulated material handling systems in the facility. In the physical world, the maintenance teams would then be repeating actions they had practiced and experienced in the virtual simulation. A key to improved productivity in the field is to be properly prepared before starting a task and then to have the necessary safety isolations clearly seen to be in place prior to attempting to open up piping and equipment. VR can help deliver this improved productivity and safety.

There is no practical limitation on the amount of data that can be contextually linked into these Data Digital Twins and VR is a critical tool to facilitate visualisation of this data. Historically, these kinds of data were only available in libraries of hard copy information or in stacks of AV storage media – and in many cases they were not easily accessible to field teams. (Large technical libraries of paper books were actually a significant historical fire risk in some LQ's.) VR means no hard copies needed, and access to the data would be available to any field and remote team members with access through the Internet to Data Digital Twin platforms in the Cloud.

Training of oil & gas operators and maintenance teams is particularly improved with VR. It has been claimed that people retain ~5 percent of what they hear in lectures, ~10 percent of what they read, and ~20 percent of what they see and hear in visual presentations (*Ref. National Training Laboratory (NTL) Institute for Applied Behavioural Science*), but with VR simulation learning retention rates increase to ~75 percent. "Retention is higher using immersive technology because people can remember all of the places and features of the plant vividly," (*Ref. J. Abel, ARC Advisory Group*). Training is also significantly quicker in timespans of months instead of years. Competencies of our operating and maintenance teams can be realised quicker and refreshed as needed wherever teams are located. And language need not be a hindrance if VR training uses visual methods to demonstrate and practice simulated physical actions.

An aspirational user scenario could involve using VR to replace conventional rounds through a facility. Imagine a remote user performing a virtual round – entering the facility's VR simulation and "walking" through the facility looking at the virtual equipment and systems for anomalies or changes. The 3D CAD model could display "heat map" style process settings for all equipment and systems (i.e. colour shading could display whether a piece of equipment or system was within (API derived) optimal IOW operating ranges or whether various level limits were being experienced). Alternately the user could look for changes (i.e. colour coded to display when and where pressures or temperatures or rates of flow or vibrations had changed (API derived) since the last user defined period of time). Distributed laser or photogrammetric scanning devices could show relative dimensional data able to be reviewed in the VR simulation where displacements, deflections, or distortion had occurred since the last user defined period of time. Distributed IR cameras could show surface temperature data able to be similarly reviewed in the VR simulation where hot things got hotter or colder or cold things got colder or hotter – where anomalies may be related to process issues or physical degradation (e.g. moisture and damaged coating under insulation). Distributed cameras and microphones around a facility could be accessed as needed, linked to various groups of equipment. Anything seen, measured, or heard on a safe VR round could lead to physical rounds by operations or maintenance field teams if needed.

31. Augmented Reality (AR) in Oil & Gas

Augmented Reality (AR) is another powerful tool that is evident everywhere today in the media and social worlds. Similar to VR in the previous section, AR also has a beneficial role in the technical world of oil and gas facilities to help deliver integrated intelligent operations and production. Deloitte describes these tools as helping “humans to interact more naturally with the increasingly intelligent world around us”.

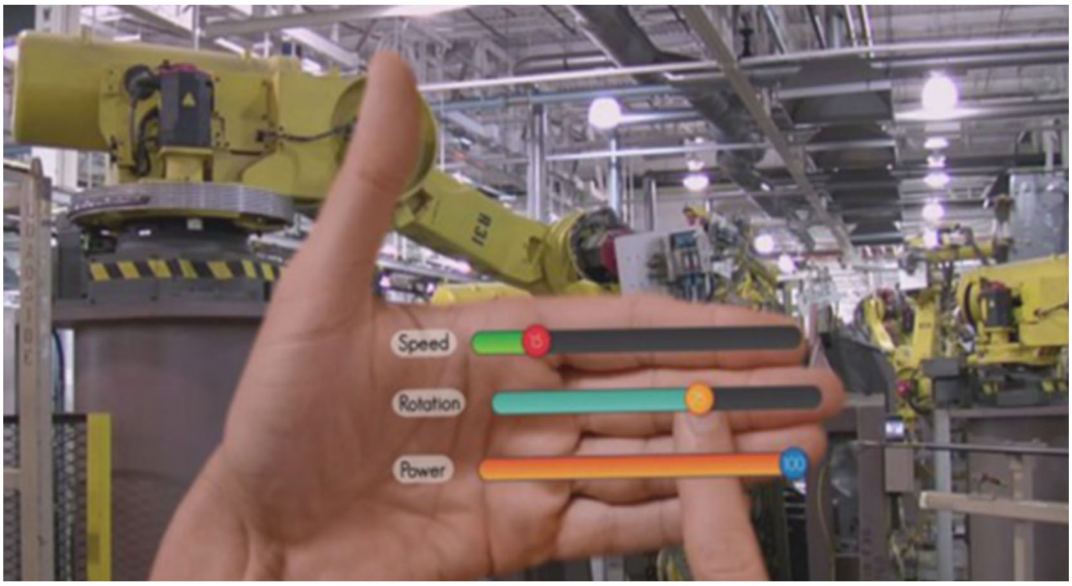
The previous section talked about virtual rounds with VR – having remote operators enter the virtual facility and perform their periodic inspections using the data available through the Data Digital Twin. Now imagine a scenario where there has to be some physical presence in the facilities (especially to do maintenance). AR will improve (augment) the capabilities of the field user doing physical rounds or complex maintenance.

The pictures above show either some form of handheld tablets or wearable devices (“smart glasses”) – both with inbuilt cameras and communications – being used for AR. The field user could walk around and scan around the physical facility whilst accessing contextual data ranging from live process data to underlying engineering or maintenance data. The AR devices can recognise the appropriate equipment or systems by scanning RFID tags, by scanning physical tag characters, by geolocation and orientation of the device, or by optical recognition (e.g. having used ML to “recognise” the shape or the equipment from most any angle). Once recognised, the AR system could link into the Data Digital Twin (in a similar manner to that described in the previous section about VR systems) to access all the contextual data and allow the user to select which data is required to be viewed or utilised.

Through the communications system, the field user could be in communication with remote technical experts whilst diagnosing performance or maintenance issues. This is one of the biggest benefits of AR for field users. We can assign multi-discipline personnel to these operating and maintenance teams, but the cost and risk of large teams on remote oil and gas facilities means that it is better to “right-size” them and supplement them with remote technical experts providing additional guidance where needed for complex instrumentation or rotating equipment for example. A common cause of maintenance issues is performing unnecessary maintenance (i.e. improperly scheduled or incorrectly diagnosed) or incorrect maintenance (i.e. using wrong tools or spares or sequence of disassembly or reassembly or testing). Field personnel can implement local overrides in packages during maintenance and forget to remove them prior to subsequent restart and operations, so remote technical scrutiny or real-time virtual access to maintenance checklists can help remind them.

The field user also needs monitoring to improve their own safety so that feedback can be given to them and their supervisory personnel – whether there are any health issues (e.g. physical impairment or capacity), geolocation, and proximity to hazardous conditions or areas (including automatic or manual directions on how to avoid). In one hypothetical scenario, “smart glasses” could help guide field users through zero-visibility situations (e.g. smoke or lack of lighting) by projecting VR simulations into the field of vision to help users select and follow the appropriate route to safety. Imagine a “Siri” or “Alexa” type virtual assistant in your headset answering queries, connecting you to remote technical experts, or summoning assistance – this is the idea of one application of AR called “connected field users”. Field users can perform normal tasks during physical rounds with the data recorded through AR – i.e. manual values turned, instrumentation observed and calibration checked, integrity assurance inspections recorded (geolocated, “visual breadcrumb trail”, though the facility, actions identified and documented).

Another hypothetical scenario is the use of “smart glasses” to recognise human gestures in the field of view (e.g. *MS HoloLens* use of finger motions (“air taps”) to indicate virtual mouse clicks or hand motions (“bloom”) to direct the AR application to “Home”). Another “gesture recognizer” idea is to hold up the palm of your hand in front of the “smart glasses” field of view whilst looking at a piece of equipment, and then a window representing a control panel for the particular piece of equipment could appear and be utilised.



Recent technical advances have even worked to utilise Direct Brain Interfacing with non-invasive “caps with electrodes to sense brain activity which is then used to trigger actions in the virtual environment (*Ref. NextMind*). A goal of “hands free operation” would facilitate the physical safety of field users whilst using AR to perform field duties.

AR is a powerful tool for supporting our oil and gas facilities field teams by better connecting them to contextualised data and remote technical expertise. It should make our field users safer, more effective in their daily tasks, and allow remote support participation by supervisory and SME personnel. The end result should be increased value.

32. Maintenance and Digital Transformation

Maintenance has been mentioned in several preceding sections and better maintenance is an important challenge to deliver the increased value we are pursuing in oil & gas facilities through the use of digital transformation tools. Value comes from reducing unplanned/unnecessary maintenance and doing maintenance right the first time:

"One study found that 86% of maintenance is either reactive (too late) or preventive (unnecessary). Best practice is 40% reactive, with a shift to predictive/ proactive maintenance. … Remote diagnostics help alleviate unneeded trips to the field. As many as 35% of these trips are for routine checks, 28% are for non-existing problems, 20% are for calibration shifts, 6% are for "zero off," 6% for plugged lines, and 4% are actually failed instruments. That's mostly ghost chasing – going out to the field and checking things that were working." (*ref. Emerson*)

Each of these preceding issues can be addressed through various tools including IoT instrumentation, Digital Twins, Data Analytics, Machine Learning/AI, API's, Virtual Reality (VR), and Augmented Reality (AR). Better availability or operational uptime can add increased value through enhanced production (less unplanned shutdowns), costs can be reduced with more efficient manning (by augmenting multidiscipline crews with remote technical expertise), reduced spare part inventories (from predictive maintenance), and quicker return to production after shutdowns (maintenance done efficiently and correctly).

IoT instrumentation is used to collect all the necessary operating data from the field equipment. "Sensors can detect 70% of failures across maintainable assets." (*ref. "The path to prescriptive maintenance", Will Goetz, Emerson, Plant Engineering, May 2017*) This data is then able to be used in Digital Twins to help monitor integrity operating windows (for extending the nominal service life of equipment) as well as assisting with the identification of impending "failure signatures". Data analytics can be running constantly (e.g. Edge analytics) or be initiated from Digital Twins (e.g. when actual performance begins to deviate from analytical predictions). Machine Learning and AI help "tune" the predictive analytics to better identify the thresholds of failure from the large amounts of data. Maintenance is improved when there is sufficient warning time of potential equipment failures (predictive maintenance) so that proper notice exists to plan spare parts, tools, and competent personnel to perform the preventative maintenance. Both field and remote users of these data streams and analytic tools would use application program interfaces (API's) (either on the Edge data/analytics or in a Cloud based Data Platform/analytics) to help identify actions (i.e. changed operational settings or in extreme cases to institute a shutdown to prevent catastrophic failures).

Virtual Reality (VR) can be used to plan and train personnel to better execute field maintenance activities. Augmented Reality (AR) can be used to "augment" the field personnel with on-line contextual data access as well as remote technical expert support where needed. Conventional physical rounds by field personnel were meant to notice anything out of the ordinary (i.e. unusual vibrations, sounds, temperatures, fugitive emissions, leaks, etc.) but now most of the same information can be gathered with IoT instrumentation and shared with remote personnel via VR – "virtual" rounds to help identify potential impending issues that may lead to failures and subsequent reactive maintenance. Data analytics will be able to identify many potential issues, but for the short and medium term, the use of people evaluating field conditions and data will continue to be important – we just need to "augment" these people and locating them remotely will also reduce costs and improve their physical safety. With sufficient operating experience, all this data (and decisions) can be aggregated with Machine Learning/AI to eventually grow confidence in more autonomous tools to adjust operating processes to extend equipment service lives (reducing maintenance) and extract more value from our facilities (less shutdowns). Information like this will also feed back into improved equipment selection and facility design and operational plans.

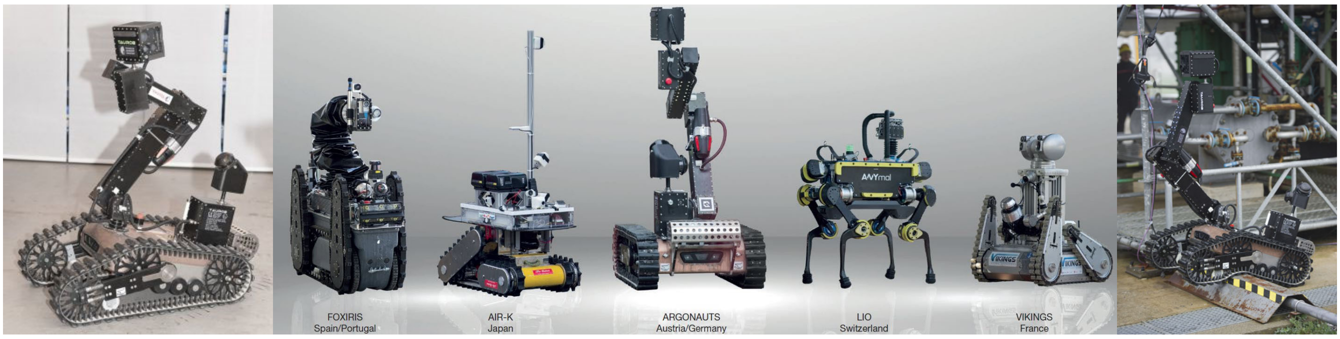
No matter how well we design and operate our facilities, eventually some maintenance would be required. Here VR and AR are able to provide improvements in outcomes. VR would be able to help train the field maintenance personnel in how equipment and systems are accessed, materially handled, opened, disassembled, refurbished or replaced, reassembled, tested, and restarted. Practice in a virtual environment has been found to be much more effective and quicker than just reading manuals or viewing audio-visual alone. It can also help maintain competence through periodic refreshment training. AR then would be able to help the field maintenance to be efficiently performed. The field personnel could review the necessary maintenance data (i.e. manuals, drawings, tool requirements) once on location; ensure equipment is properly isolated (i.e. real time process conditions inside the equipment or pipework adjacent); and, if needed, be in contact with remote technical experts (i.e. in case of difficult diagnosis of issues or complicated procedures to maintain). Maintenance experience has shown that preparation and support like this helps ensure more successful outcomes in a safer and timely manner (done right the first time).

"*The largest single controllable expenditure in a plant today is maintenance, and in many plants the maintenance budget exceeds annual net profit*." (*ref. DuPont*) This is a good reminder of the value of better maintenance.

33. Robotics in Oil & Gas

Robotics is an interesting topic – the term can refer to a wide range of technologies from computer systems using AI to industrial robots performing physical tasks. Advances in distributed computational power and speed and reductions in memory storage size and power requirements has meant today's robots can be fairly autonomous whilst wirelessly receiving and transmitting data and performing tasks. It has been estimated that there were over 2.6 million industrial manufacturing robots in 2019. These robots have improved precision, quality, reliability, and HSE in many factories (*ref. Deloitte*).

Robots can be as simple as mechanized devices within an equipment package, but they can also be humanoid robotic systems (ref. Woodside's testing of NASA and GM's R2C3 robot for offshore platforms). Robots can also be the more familiar drones and AUV's/ROV's used today onshore and offshore for our oil and gas facilities.



Total sponsored the ARGOS Challenge with French ANR from 2014 onwards with five teams from Austria and Germany (ARGONAUTS), Spain and Portugal (FOXIRIS), France (VIKINGS), Japan (AIR-K) and Switzerland (LIO). These teams tested robotic prototypes (pictured above) in Lacq, South West France on a competition site representative of Total's facilities and operating conditions. This was a very successful competition with great sponsorship and input. These robotic devices were able to traverse simulated oil & gas production facilities through conventional human access routes to perform various tasks and capture data. Total subsequently deployed the ARGONAUT robot to their onshore Shetland gas plant and then offshore on their Alwyn platform. Total's robotic work continues well.

Robotic devices could operate using various scanning tools including laser, infrared, ultrasonic, and microwave sensors. These sensors can help guide the robot through a complex facility avoiding obstacles. In the case of an unforeseen situation, a remote human operator could be called upon to use a visual camera ("shared autonomy interface") to help extricate the robot from a difficult situation (or else a field operator could come in person to the location to assist). In either case, an extremely good communications system is required to wirelessly receive and transmit data. These communication systems were covered in an earlier section. Computational capability onboard the robot can vary – analogous to fixed equipment, the computing can either be "Edge" or remotely based – so depending on power requirements and task duration, the computations and data processing can occur at either location and data can be exported in real time or downloaded later.

Currently oil & gas field robots have been trialled with mainly inspection capabilities, but the ability to intervene is being progressed rapidly. Physically doing interventions will require manipulators which would increase power requirements so better batteries and/or the potential ability to "plug in" power cables at distributed locations will help this capability. Imagine a large oil & gas facility with many hundreds of manual valves or battery powered wireless devices or lights – the manual work required to periodically turn valves, replace batteries, or replace lights is tremendous. A robotic device should be able to do a lot of this manual work as well as record the actions in the maintenance databases automatically.

Large floating facilities can have hundreds of compartments which need to be periodically inspected – this ranges from void compartments, to ballast compartments, to oil storage compartments. A large TLP in the GoM required a team of 4 people working almost continuously to perform these compartment inspections and all data had to be manually recorded – imagine robots entering these compartments, collecting and recording the data, and safely exiting. Large FPSOs would have similar challenges and the cost of inspection personnel and their safety considerations are significant. So in both cases, robotic devices could offer operational cost savings and improved field worker safety profiles.

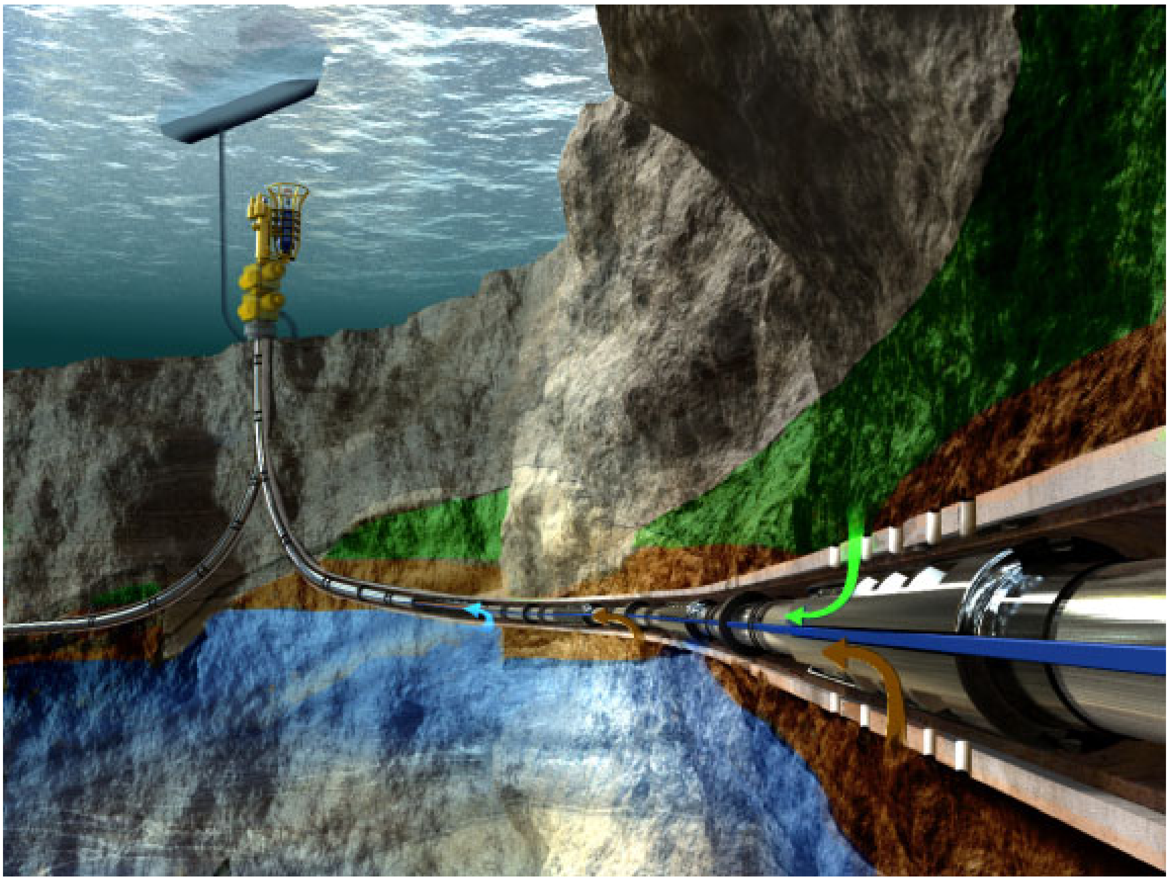
Another cost saving idea may be the distributed lighting in oil & gas facilities. Lighting is used for human eyesight and video cameras – but maybe permanently installed lighting is not always needed. Continuous real time monitoring of facilities can use laser, infrared, ultrasonic, and microwave sensors where visible spectrum lighting is not required. Then when lighting is required somewhere in the facility, a robotic device can bring out the lights from a docking location elsewhere – this is actually what happens underwater when an ROV comes to inspect or intervene in subsea facilities and it has its own light package – subsea facilities do not have permanently installed lighting.

Ultimately a goal is more unmanned facilities, safely operated fairly autonomously, monitored remotely, inspected and maintained by robotic devices. This is an ultimate challenge of Integrated Intelligent Operations & Production.

34. Subsurface IIO&P

Throughout earlier topics, it was frequently mentioned that most of the improved value applying Integrated Intelligent Operations & Production to our oil & gas developments would come from Subsurface: getting more hydrocarbon molecules out of the ground quicker, more reliably, staying on plateau longer, and having slower decline curves. We have seen that there are tools available to analytically simulate the subsurface reservoirs.

With IIO & P we have IoT instrumentation to collect field data, both subsurface and within the surface facilities. We understand there are analytics which can be performed on this data to gather insights to identify decisions necessary to capture more value. We know that smaller, empowered multidiscipline teams close to the asset can utilise this information and efficiently improve the performance of our subsurface assets. Workflows have to change however.



(*Ref. Emerson*)

Downhole in a reservoir's wells, we have various instruments measuring pressures and temperatures. At the surface in the wellheads and trees, we have more instruments measuring pressure, temperature, and sometimes composition (e.g. multiphase data). With all these IoT devices, we can calculate a well's performance including pressure drops, rates, and compositional changes. Aggregating a reservoir's wells, this data can be used to compare physics-based models of theoretical reservoir performance with actual performance to "tune" the models. Then during production, the impacts of potential changes in operational inputs (e.g. choke settings), can be evaluated first analytically then applied in the field if production looks able to be improved.

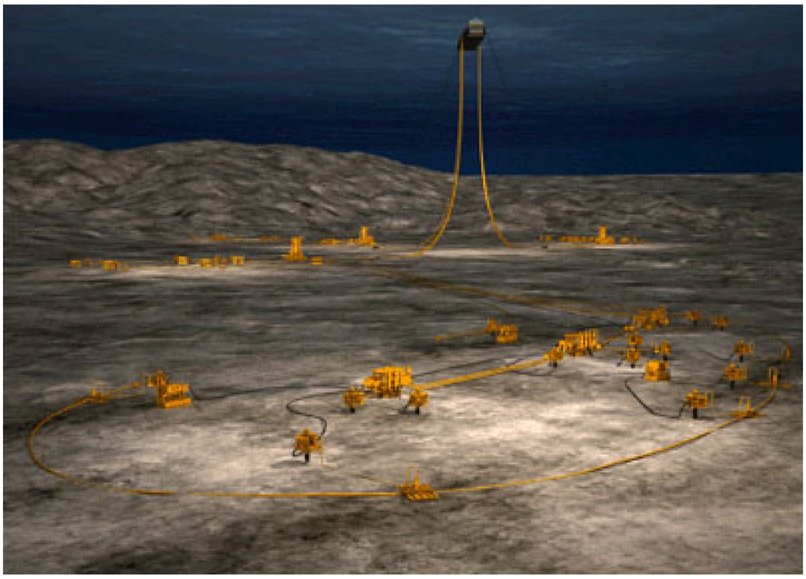
For a percentage of IoT devices there can be interruption (or corruption) of data especially in the subsurface environment (i.e. hot, high pressure, corrosive fluids). Surface instruments can often have the ability to be designed to replaceable, but these subsurface instruments (or their downhole data cables) can be very expensive or effectively impossible to replace. So if an instrument starts giving anomalous readings, first it has to be checked to see if the readings are revealing some change in the reservoir fluids, then it has to be checked to see if these readings are instrument "drift" (prior to eventual failure). Using a Digital Twin of the subsurface model and surface facilities, the reading of an individual instrument can be replaced by a virtual instrument reading (if other working instruments have stayed aligned with the Digital Twin results). Usually Safe Critical Element (SCE) instruments are in the surface trees with some redundancy, so that if one SCE instrument fails, there is still a working instrument. Sometimes key instruments are ROV retrievable and replaceable. The use of virtual instrument readings is a powerful tool to help avoid unnecessary or impossible maintenance tasks on the other instruments.

A complex reservoir with various combinations of oil, associated gas, gas caps, water injection, aquifer support, and stacked discrete reservoirs can be challenging to simulate. Sometimes these reservoirs may have compositional variance (i.e. different amounts of gas or compositions of oil) or seismically un-visualized compartmentalization. Subsurface teams will do their best to model all this and make simulation models (that are tested with stochastic variations of key variables) but ultimately the real world production will be monitored and checked against these dynamic simulations. Just to make it more complex, well designs can add additional flow assurance related production variations (i.e. liquids slugging in horizontal wells, hydrodynamic (gas) slugging in wells, or condensate banking around gas/condensate well completions). The dynamic simulation models will need to be carefully adjusted to try to match the actual production data from these wells under a particular set of operational settings. Machine learning tools are being used to make this easier and quicker to adjust the models with the real world results adjusting the various modelling parameters. IoT data feeds into analytics and then onwards into updated Digital Twins. This allows the asset teams to consider how to further adjust operational settings to capture more hydrocarbon molecules sooner.

Data driven models are a newer concept over the past few years. These models focus on analysing a "high-dimension data space" and finding "connections between input and output without definitive knowledge of the system's physical behaviour" (*Ref. "Enhance Oil & Gas Exploration with Data-Driven Geophysical and Petrophysical Models", K. Holdaway*). As some reservoir models have become so complicated (e.g. large number of operational and geological parameters), the time and cost to perform simulations has become impractical to perform detailed uncertainty analyses to test the impact of key variables on a range of production scenario profiles. Data driven models are becoming a "tool to overcome challenges related to dynamic assessment of uncertainties during history matching of recovery processes and signifies the ability of data-driven analytics in future performance prediction of various oil and gas reservoirs" (*Ref. "Data-Driven Analytics for Oil and Gas Reservoir Production Forecasting", E. Amirian*). These models obviously rely on a lot of data, so initially models will likely remain physics based (adjusted with data as it becomes available) until such time as data-driven models can assist, first by history matching, then predicting how improvements in value might be possible by adjusting some of the operational well settings.

35. Subsea Oil and Gas Facilities IIO&P

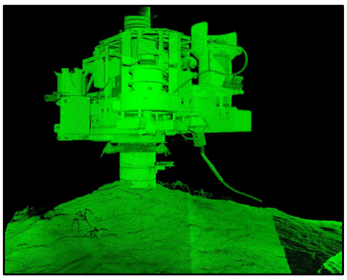
A lot of discussions about digital transformation for oil & gas surface facilities are concentrated on the topsides process facilities. But on the seabed below can be hundreds of millions of dollars' worth of production facilities that are absolutely essential to safe and efficient extraction and operations. Subsea facilities will benefit from improvements associated with IIO & P.

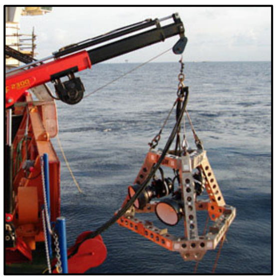


Subsea facilities have many common elements to topsides facilities like valves, piping, instruments, and safety and control systems. But there are also some important differences: (1) nobody "walks" around doing periodic rounds (maybe only infrequent ROV surveys); (2) not easy to monitor "visually" due to the properties of the seawater (i.e. suspended solids, lack of light, and the presence of biomass and nutrients). Cameras need lighting which needs power – could be done, but requires more capital expense and maintenance. Infrared cameras have issues with seawater attenuating the infrared light spectrums, so more difficult to scan for thermal anomalies. It is not possible to use gas leak detectors (i.e. electrochemical, photoionization, IR, or semiconductor types) and acoustic (ultrasonic) detectors would have difficulty with attenuated sounds from small leaks underwater. Small oil leaks would similarly not very easily be spotted (visually or thermally).

Fortunately we do have many useful IoT devices to gather information similar to that captured in topsides facilities. We have pressure, temperature, vibration, valve positions, and compositional metering (single phase and multiphase) instruments to monitor any changes due to operational or reservoir reasons. We can monitor changes in (1) the hydraulic pressure to open and close valves; (2) the time it takes to open and close valves; and (3) pressure drops across chokes / control valves. We have the ability to capture (measure) as-built / as-installed configurations or positions of flowlines and umbilicals to be able to later inspect for any changes. So a lot of data is available for input into Digital Twins of these subsea facilities.

There are some visualization tools available such as Subsea LIDAR lasers – used for as-built / as-installed / in-service surveys (incl. settlement or expansion); measuring vibration (with a controllable beam, able to scan and dwell on a point of interest to obtain linear and rotational movement including vibrations up to 20kHz); or even to detect some leaks (with fluids of different reflectivity) (*Ref. 3D at Depth* *www.3datdepth.com* image and equipment pictures on next page).





The Advanced Imaging and Visualization Laboratory (AIVL) at the Woods Hole Oceanographic Institution (WHOI) has worked with Marine Imaging Technologies (MITech) to develop a multi-function, underwater imaging system (Hydrus) capable of generating ultra-high definition television (UHDTV) video, 2-D mosaic imaging, and 3-D optical models of seafloor objects and environments. A self-contained retrievable lighting package could be installed to provide battery powered lighting as needed. These types of tools can be used in real-time (e.g. permanent installation in the subsea facilities) or for periodic ROV inspections to observe subsea facilities and measure any changes that might need input into the Digital Twins or even require some kind of physical intervention.

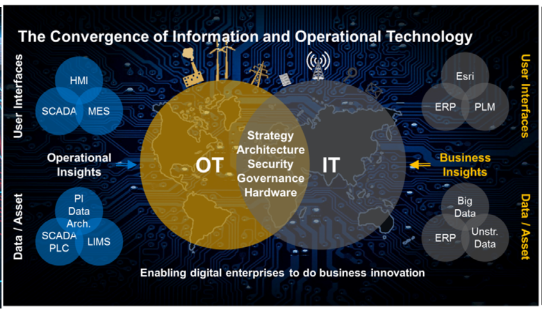
Another potential imaging tool is high resolution coherent sonar with ultrasonic sounds, a synthetic aperture, and Fourier based imaging algorithms - now being trialled to check the ability to image better where visual or infrared cameras are not able to work. Synthetic aperture sonar can yield an acoustic image with a resolution down to 2 cm over ~350 m; also allowing detection of gas or certain fluid leak-related features (~10 times the resolution of conventional sonar). These imaging tools can help provide useful information to remote operations teams.

(Ref. GE Village Animation (2016), J McAlister)

So subsea facilities can have a significant number of useful IoT instrument devices recording critical data necessary for safety and analytics. With Subsea Control Modules (SCM), it could be possible to utilise Edge analytics processing data to help reduce bandwidth requirements of data flows to remote users. Edge computing could be used to provide more autonomy for certain safety and control systems' intervention actions to help deal with flow assurance issues that may arise. As subsea facilities continue to incorporate more processing (i.e. water separation / re-injection; heat exchangers (or heaters); pumps; or gas compression) we will need to have more ability to monitor and make changes to keep production stable and help minimise trips or shutdowns. The use of IIO&P can improve safety and value in the performance of our subsea facilities.

36. Cybersecurity in Oil and Gas Facilities

In light of so many news reports of computer systems hacking, phishing, identity theft, denial of service, and ransomware, Cybersecurity is a good topic to examine in a little more detail. Are we going to be alright from a cybersecurity risk perspective with some of the applications of Digital Transformation described in this document? The short answer is "Yes"- if we adopt hardware and software systems available to help protect our oil and gas facilities and we make some changes in how our teams work within our facilities. There is good technical expertise and solutions available in the market to help protect our equipment and facilities, our communications systems, our Cloud platforms, and our remote user computer access systems from fraud, sabotage, interruption, unsafe operations, and/or other safety violations.



Our oil & gas facilities incorporate both Information Technologies (IT) and Operational Technologies (OT). IT is focused on the storage, recovery, transmission, manipulation and protection of data (and has typically been more advanced in terms of security levels). OT is focused on the control of facility processes or their change through the monitoring and control of devices (and has not had significant security levels due to previously being "unconnected"). With Digital Transformation, we are seeing IT/OT convergence as the data-centric systems merge into operational technologies. Here lies some of the cybersecurity risks. The various systems have software and hardware protections, but there have been gaps and lack of understanding by all participants where some of the vulnerabilities exist. State of the art firewall facilities ("boundary defence") and malware detection software may not be enough. Security operations and incident response processes may not detect risks for significant periods of time and may not be able to quickly resolve any issues. Physical and virtual entry points for cyberattackers can range across the facilities and throughout their life cycles from procurement to construction to commissioning to field operations. McKinsey tells us that with so much interconnectivity in IT/OT convergence, our cybersecurity must be "comprehensive, adaptive, and collaborative".

Equipment and Facilities (OT security) – there can be thousands of IoT devices inside our facilities as well as control panels and distributed computing equipment – all of which face risks as they are exposed in potentially unsecured environments from suppliers to fabrication facilities to shipyards to the field. People could insert modified hardware or software into these devices or equipment along the way. Rules and "signature" based software systems can be useful for protection, but as threats evolve (e.g. "zero day threats") another form of protection has been developed. IoT devices have expected behaviour which can be monitored with unsupervised machine learning analytics to "learn" what "normal behaviour" is and what are "unauthorised deviations" (i.e. receiving or transmitting information to other locations, changing sequences or timings of operations, or the lack of correct responses to specific instructions – "anomalous behaviour"). Dark Trace calls this new protection Autonomous Response AI and IBM calls this Cognitive AI security. Hardware based security solutions can involve restricting external access to sensitive areas (e.g. blocking inputs to devices to make unauthorised changes), preventing the flow of instructions into an IoT device (e.g. only allowing data to flow back one way), or requiring additional hardware connectivity to be used to make changes in IoT devices or distributed computing equipment.

Communications Systems (Connections security) – communications can range from copper based (wiring) to fibre optic to wireless within a facility. At some point the communications, especially for remote facilities, could connect to external teams through microwave or satellites. At each gateway / transition point there could be vulnerability – satellites are generally publically accessible and their uplink or downlink earth stations or signals could be accessed without the oil & gas facility operator being aware. Telecom network security protocols have been targeted previously so there have been some weaknesses. Data encryption is an important protective measure along with proper access authentication methods and tunnelling where feasible to help prevent access at these entry points into the upstream or downstream systems of our oil and gas facilities.

Cloud Platforms (Enterprise Application security) – as described in a previous topic, the Cloud can range from public to private and may be hosted externally or internally. The Data Platform security challenge is to prevent access and interference with data or software within the particular Cloud. Analytics need clean, uncorrupted data that is reliable since actions and decisions will depend on this data. Analytics are run either within the Cloud or with API's accessing data in the Cloud and run externally (e.g. within an equipment supplier's technical team). Decisions to adjust operational settings or to prepare for critical maintenance can be compromised if security in the Cloud Platforms is compromised. In a similar manner to some of the cybersecurity protection methods and tools described above, visibility of all users and devices that have the ability to access the Cloud needs to be provided, security needs to be natively integrated into the Cloud to reduce the "attack surface", and authentication of authorised users and methods of acceptable data manipulation needs to be continuously controlled and monitored.

Remote User Computer Access Systems – data has been gathered, maybe edge processed, communicated, and now resides in a Cloud Data Platform – remote users now need to access it. These users can use API's (~83% of web traffic according to Akamai) to enter into the data platform and extract (and sometimes manipulate) the necessary data for whatever analytics or enterprise management purpose is desired. These API's unfortunately greatly expand software attack surfaces so they can be a significant cybersecurity risk especially if made over public networks. There are cybersecurity API's that allow cybersecurity teams to check the identities of remote users by being able to "explore and audit DNS records, IP addresses and domain names, finding any abnormal changes to DNS infrastructure to prevent harmful activities like domain hijacking, and also to find stale DNS records, and review SSL certificate information" (*Ref. https://securitytrails.com/blog/cyber-security-apis*). Access management of these remote users must be periodically checked, updated and authenticated using virtual private networks (VPN), network access control (NAC), and user multi-factor device (e.g. 2FA with security tokens). There will be potential remote users all over the world ranging from technical SME's to suppliers to asset teams and these connections are a cybersecurity risk which has to be weighed against the benefits of remote users supporting small field teams.

The threat of obsolescence in hardware and software is effectively another type of cybersecurity risk. When our engineering teams design and specify Supervisory Control and Data Acquisition (SCADA) systems and the IoT devices used to gather relevant data, there can be a considerable period of time between when the equipment and software is purchased, installed, and used. With facility service lives ranging up to 20-30 years, certain equipment and software could become unsupported by the OEM suppliers. We could risk having our systems become obsolete and unable to be easily repaired or modified without extraordinary efforts or maybe even impossible. There are documented instances of complete SCADA systems having to be replaced later in life due to the inability to get spares or servicing done. Older hardware and software may not have modern cybersecurity protections. We need to design physical systems to be updatable (feasible for Remote Terminals Units (RTU) and Human Machine Interfaces (HMI) but difficult for Programmable Logic Controllers (PLC's)). Software needs updating, but software patches and improvements often stop being supported after a number of years. Open-source software is one idea to try to remain updatable but there are also specialist aftermarket suppliers like More Control UK Ltd. who can write software updates for some proprietary control systems.

People are another cybersecurity risk – in a recent survey of several hundred cybersecurity professionals, the SANS 2019 State of OT/ICS Cybersecurity Survey revealed that 62% of the respondents believe people are the greatest risk. "People" can mean insiders (i.e. employees or contractors), visitors (e.g. service technicians), or intruders (e.g. nation-state bad actors) – either malicious or just careless (errors). People using mobile devices (smart phones, tablets, or laptops) and wireless communications solutions (Bluetooth, "Wi-Fi") bring risks. USB flash drives have previously been identified transmitting virus software and malware, and they are still very commonly used and have been found in "unconnected" OT systems where they caused problems. Portable hard drives can similarly transmit the same risks. In remote facilities, people will want to use personal devices to connect with families / friends and utilise the Internet for social purposes, so oil & gas IT/OT systems need to isolate social users within a facility from connected systems (typically with separate firewalled channels).

So as you can see there is a range of cybersecurity risks and we need support from both IT and OT teams working with specialist cybersecurity consultants and suppliers to properly protect our oil & gas equipment and facilities. The benefits of Digital Transformation as delivered through Integrated Intelligent Operations and Production are so attractive that the additional effort is worthwhile. The rapidly increasing data flows coming from millions of IoT devices offers significant potential value if used properly and protecting this data from cybersecurity risks needs to be a key component of the overall solutions.

37. Integrated Intelligent Operations & Production for Oil & Gas Facilities

We reviewed the challenges facing the industry and some of the areas of where additional value could be captured from our developments by adopting best practices from IIO&P: (1) Recoverability (from our Reservoirs); (2) Reliability (of our equipment and facilities); (3) Operability (equipment and facilities again); and (4) Maintainability (equipment and facilities again). IIO&P was defined as "Integration of people, process, and technology to make and execute better decisions quicker".

Throughout these topics it has been emphasized that IIO&P is not just about applications of new technology – it is about people, culture, and better ways of working. One of the reasons for writing about these topics was to help companies be more successful with the application of IIO&P – there is an unfortunate statistic that 70-80% of companies fail in their efforts to adopt these solutions. Unsuccessful pilot programs, lack of change in team composition (e.g. we need small, multidiscipline, "agile" teams closer to the assets), unchanged workflows (i.e. excessive time gaps between data and analytics, hierarchical decisions made by stakeholders far from the data and asset, or lack of operations input to insights), or failing to look at the systems holistically (e.g. subsurface + surface facilities + process facilities modelled together) have all contributed to these failures. It does not have to be this way, there are companies who have been very successful with digital transformation and captured significant additional value. Oil & gas companies can be "fast followers" and learn from these successful companies.

Material new investments are not required – most of the capital cost is already included in the physical facilities, the existing safety and control systems, and the communication systems used with our field teams. It is claimed that up to ~99% of existing data streams (from current IoT devices in the equipment) are passing through oil & gas facility control rooms without being used for performing analytics, finding insights, or helping to make decisions to change how to better operate or maintain these facilities. We are recommending collecting this data (in the right fidelity, cleaned, and contextualized), possibly processing it on the Edge (to reduce bandwidth requirements for data transfers), communicating it through satellites, and transferring it into data platforms in the Cloud. Once in the Cloud data platforms, a whole range of remote users from technical SME's to suppliers to asset teams can access and manipulate this data to help our field teams find ways to capture more value.

Subsurface asset teams will be one of the biggest beneficiaries to get better data quicker which they can use in dynamic simulations of the reservoirs to see how actual production is progressing compared to physics based models, then adjusting their models as required and investigating potential changes to well settings. Experience has shown us that Subsurface teams need to work with Surface Facilities teams on Digital Twins models to properly optimise production without causing unforeseen facilities issues. It has been estimated that developments can recover an additional 6-8% from reservoirs (i.e. production profiles with earlier ramp-ups, longer duration plateaus, and slower decline rates).

Surface facility asset teams have faced difficulties in getting up to their nominal design production rates in the first year of production with examples of North Sea developments struggling to achieve ~80% uptime efficiency even after 6-12 months of early production. During production, uptime efficiency is adversely affected by operational issues including control systems needing to be completed and then tuned to suit actual field production parameters and constraints. Physics based production models have needed to be adjusted to better model how the wells react to various equipment settings. Liquid and/or gas fluctuations can affect topsides equipment performances. Operations field teams generally do a good job of learning how to adjust their facility control systems but it takes time which means reduced early production and significant deferred value. There is a significant prize in this first year of start-up if companies can make use of the technologies, data, and work practices available.

Having dynamic simulation Digital Twin models prepared in the design phase helps engineers better design the facilities and control systems including investigating predicted optimum integrity operating windows to aid in equipment selection. These Digital Twins are then able to be modified to become Operational Training Simulators to train the future operating teams – and during this training there is an opportunity to further test and improve the control systems using these operators' experience. Finally these Digital Twins are able to become benchmark tools during operations to check actual production results against predicted results – enabling models to be tuned as well as gathering performance data of the equipment for later use (Machine Learning and AI). Two models can be used – one for monitoring actual versus predicted IoT data results (to check accuracy of the model) and one for "what if" scenario work (to investigate if potential changes to well settings or equipment settings can improve production).

During the production life, equipment and systems begin to naturally degrade with time and the challenge is to understand how to extend maintenance periods (by adjusting operating settings or procedures) as well as to prepare for predictive and preventative maintenance (e.g. not just waiting until things fail). Significant value is able to be realised by these IIO&P maintenance related tools and practices.

Adopting best practice from IIO&P will also improve safety. Instead of being reactive and mitigative, we have the opportunity to be proactive and preventative. Part of technical safety is about understanding how our wells, equipment, and systems are functioning, especially with respect to upsets or abnormal performance that could lead to loss of containment. Having better monitoring and diagnosis of this performance gives us more insight ahead of time that something needs attention, adjustment, or even shutdown. Field personnel are busy and more physically at risk when they are in the field, so they should be supported by remote technical teams in operator, contractor, consultant, or equipment supplier offices – digital transformation provides many tools (i.e. IoT devices, Cloud Data Platforms, Data Analytics, Machine Learning / AI, Digital Twins, Virtual Reality, and Augmented Reality) to facilitate this remote monitoring, support, and diagnostics. Facilities should have reduced manning where the primary function of personnel is to perform preventative or routine fabric maintenance.

Hopefully these topics have helped potential users especially owners and operators to better understand the digital transformation tools and work practices available to help capture more value through Integrated Intelligent Operations and Production of our oil & gas development assets. There are a lot of good companies, contractors, consultants, and suppliers who can help provide these tools.