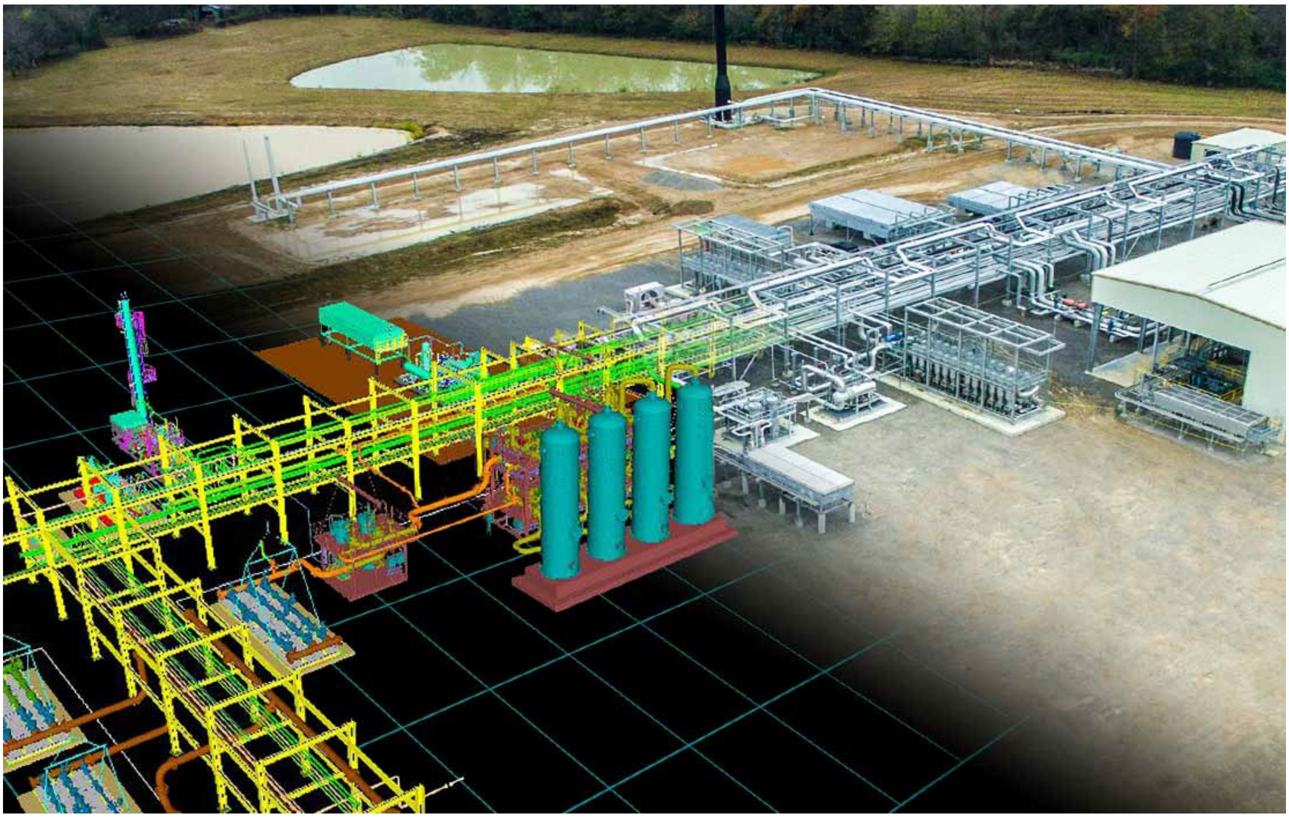
Integrated Intelligent Operations & Production: Remote Facility Developments

Volume 2



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Dedication

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 – Energy Industries are fortunate to be able to access so many of these solutions to help capture additional value from our Remote Facility developments.

Volume 2

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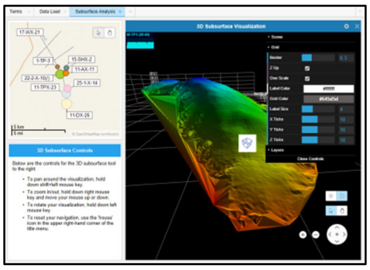
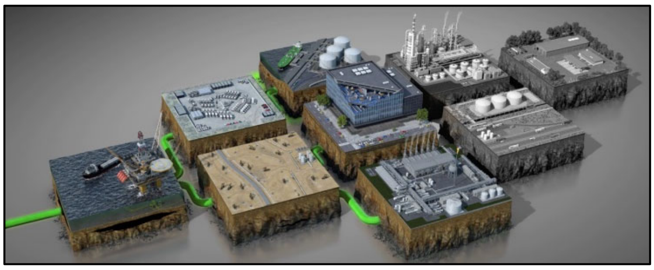
1. Prospects for Integrated Intelligent Operations & Production

After an introduction to IIO&P, it is reasonable to discuss and consider the prospects for successful adoption of the underlying technology, tools, workflows, and culture.


An article in a recent *Offshore Engineering* magazine[1] identifies the "prize" of digitalization technologies but also the challenges we need to face and surmount. First, quoting Wood Mackenzie, it is stated "Size of prize is enormous; (improved) HSE (health safety and environment), cost saving and value increases in assets and companies. Wood Mackenzie estimates $40 billion could be saved in operating costs in the upstream industry per year (of a total $356 billion in 2018)". Digital transformation at scale is a big challenge according to WoodMac[2] but it appears clear that our industry has generally adopted it as a strategic goal. The challenge of big data is significant and companies must decide how to gather, process, and utilise it more effectively and crucially some of the needed cultural changes have also been identified even if not actioned enough yet. These tools cannot really be successfully used in existing oil & gas industry organisations without changing workflows and the roles of people in our asset teams.

As noted previously, there has been a significant amount of failure in pilot programs. At a technical conference in the past year it was stated that up to 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. A common root cause of these failures was unchanged culture – multiple single discipline teams remained poorly connected with each other, workflows remained as before, and top down hierarchical decisions were made without proper reference to operational teams closer to the assets. Better insights need field operational teams working with remote technical support teams and data scientists (to help make adjustments as we go along to the digital transformation tools to make them more effective).

Potential users are faced with tremendous amounts of available technologies and tools – which ones should be selected from the long list of potential suppliers? A typical end user is faced with a large number of technical offerings, many of which have good features and capabilities, but it is the intelligent integration that matters. Not "data for the sake of data" but rather working backwards from the desired value capture based on decisions from insights derived with analytics on the underlying data. Data has to be the right data, in the correct fidelity, cleaned, maybe pre-processed on the Edge (to conserve bandwidth), potentially transmitted to a Cloud data platform, and there made accessible to a range of technical teams. Insights have to be based on reasons why, not just based on mathematical correlations – knowing why a change is needed in how a system is operated is more powerful than just knowing a change may theoretically produce an improvement. There is a difference between observing correlations and understanding what the observations are telling you. Cross-functional agile teams using Digital Twins can

[1] https://www.oedigital.com/news/476381-big-data-or-big-hype
[2] https://www.woodmac.com/news/feature/digitalisation-upstreams-silver-bullet/

test how different decisions might affect production outcomes, and then examine whether there is a direct causal link. We need to ensure we move from intuition based to evidence based decision making.

Some potential users (anecdotally up to 50% according to a recent conference roundtable discussion) worry about cybersecurity and it has affected their potential adoption of digital transformation technologies. IT/OT convergence has meant our OT systems are potentially more exposed to risks (whether malicious or just careless (errors)). Fortunately there are multiple good hardware and software protections available to help us, but they need to be "comprehensive, adaptive, and collaborative" – layered and updated and constantly improving. The prize is so significant that investing in proper cybersecurity (with the corresponding IT/OT security specialists) is cost effective. The path of data from IoT devices to eventual storage in the Cloud contains a number of attack surfaces which each need to be identified and protected and these risks can be inside third party service providers outside of the asset team's direct control. With appropriate technical support however, cybersecurity risks are being managed.

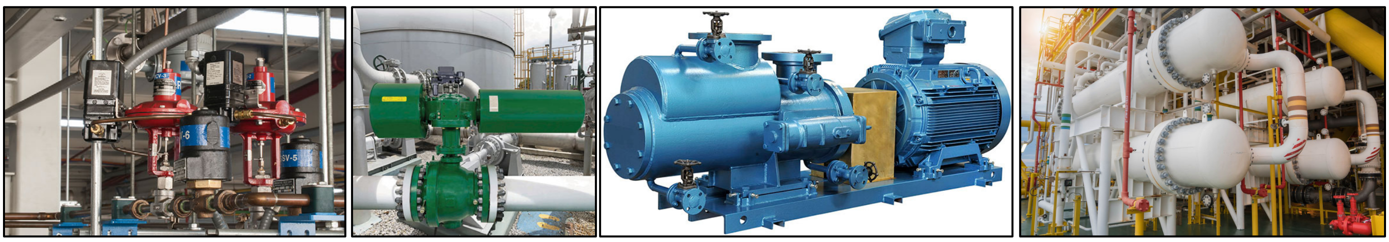
Some potential users face potential communication challenges. Existing facilities and some new facilities are often only provided with "vintage" VSAT (with significantly lower bandwidth) satellite communication systems. In fact the cost of satellite systems has dropped significantly with large numbers of high-throughput satellites (HTS) becoming available – and these satellites have increased from VSAT to HTS to VHTS to UHTS. There is no technical reason not to consider high bandwidth systems for lower cost than previous lower bandwidth systems. Another improvement is the ability to contract for managed satellite communications – no need to lock into a dedicated satellite, users can contract for the transmission of data and let the service company contract primary and back-up services which offer technical and commercial benefits as well as better risk management. Recognising that bandwidth demand would have a natural tendency to grow as users discover the benefits, it is wise to pre-process IoT data and optimise Edge analytics to help manage potential bandwidth growth whilst still accessing the benefits of higher bandwidth. Nobody should be recovering data from remote facilities in portable hard drives except as emergency backups. Time is critical for remote users to access the data to help capture value for the assets. Subsurface optimisation can deliver 6-8% more recovery of production which is material value if performed in a timely manner so that well equipment settings can be adjusted closer in time to the data receipt. Remote asset teams can perform integrated production management simulations and identify how improvements could be made by field operations teams in the well equipment settings.

A consistent message of the past year has been that culture and workflows need to change – this message has been repeated in publication after publication in our industry – but it doesn't seem to happen enough in many organisations. One successful oil & gas operator spent ~50% of their digital transformation budget in adjusting workflows, correctly recognizing this was a key challenge. Conventional hierarchical (e.g. top down decisions) organisations or large siloed (e.g. subsurface separate from subsea separate from surface facilities) organisations seem resistant to organisational change without strong executive leadership clearly supporting the cultural change. People and organisations may have been successful with prior organisational models, but "digital transformation" is about the word "transformation". You cannot "move the dial" on value capture without making more radical changes. Smaller, multi-functional agile teams closer to the assets are needed with full empowerment to make changes to workflows, decision making, and ability to iterate through solutions. This is not an IT team any more than it is an Operations team – it will succeed with multiple disciplines involved as well as data scientists to help make changes. There will be some less than successful decisions, but quick iterations ("scrums") can make changes and keep reacting as the dynamic simulations, analytics, and operational settings are tweaked to find the best solutions to capture increased value – it might be increased uptime, better maintenance, higher well production, or less interruptions. These cultural changes are familiar ways of working in some other industries, who have adopted agile practices, but they are new to the oil & gas industry and so they need coaching and support. Digital transformation to deliver integrated intelligent operations and production is not just some purchase of new technology or tools – these are actually some of the easiest parts of the solutions – it is how the teams and organisations work differently with the data and decisions. We want to stop having pilot programs fail and we want to start making incrementally successful changes in work practices and outcomes. Good help is available to succeed in these efforts and hopefully these two volumes will help those who may be less familiar with some of these solutions.

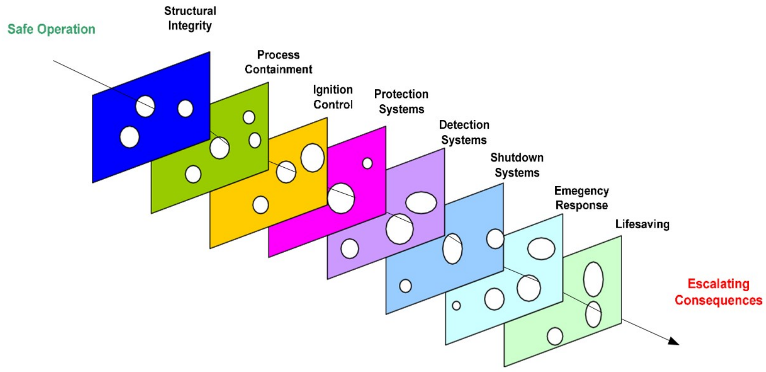
2. Data Guidance for Digital Transformation

"There is just too much data" - that was one of the comments in a recent technical conference. As noted previously, McKinsey states that up to 99% of data flows through our facilities unused for anything. It does not have to be this way, and there does not need to be "too much data". Unfortunately some data is collected almost without thought for what is needed or useful. Collecting and storing mass quantities of data without regard for how it should be used is not that uncommon (and may lead to the comment above). Major technology providers want to sell data systems including vast amounts of online and offline storage, but users need to think about what data is going to really be meaningful for analytics. The right data has considerable value.

Data from an existing Integrated Control and Safety System (ICSS) is normal data that is useful for both field and remote teams to see how the facilities are being operated within safety and control related parameters and integrity operating windows. ICSS data is useful for Alarm Management analytics to ensure best practice operating procedures are being followed. In the North Sea, a study of compressor trips revealed a significant percentage of operators needed supplementary training to improve their control responses to routine process alarms to reduce unnecessary shutdowns. Dashboard data from systems like *OSIsoft PI* is useful for other remote technical users especially for comparison with theoretical data results from a process Digital Twin. A dynamic simulation model from subsurface to subsea to surface facilities will have numerical results at various points within the model and the actual PI data from these same points can be used to check the model. In early years of a facility the theoretical model results will need to be "tuned" to align with the actual physical results, then then later in life if the theoretical readings start diverging from the actual physical readings it can be an early indication of potential equipment or instrument degradation which might need more attention. Data streams from the ICSS and the PI systems are routinely able to be captured and used for these purposes and the bandwidth requirements are not usually too large for communications.



Safety & Environmental Critical Equipment (SECE) inside our oil & gas facilities are critical items required by most safety cases to have an integrity assurance program. Reasonable numbers of SECE are a good place where users should focus on more detailed analytics to help provide increased assurance.



The next priority should be Production or Operations Critical Equipment (PCE or OCE) necessary to keep production continuing ("operations integrity" which is value). An example of a criticality rating[3] that could be used for evaluation of a particular piece of equipment is shown. Essentially this is a risk management process to assess likelihood and consequence of failure, and should be performed "unmitigated".

Criticality Rating	Consequence of Failure/Impact on Production
1	Shuts down the entire operation for more than 24 hours (or the equivalent lost production of the defined shutdown through a slowdown or unsaleable quality)
2	Shuts down the entire operation for up to 24 hours or shuts down more than one production line for more than 24 hours
3	Shuts down more than one production line for up to 24 hours or shuts down one production line for more than 24 hours
4	Shuts down one production line for up to 24 hours
5	Shuts down one production line for up to 8 hours
6	Shuts down one production line for up to 2 hours
7	No production loss; maintenance costs exceed $10,000
8	No production loss; maintenance costs up to $10,000

Likelihood

Medium	High	High	Extreme
Low	Medium	High	Extreme
Low	Medium	High	High
Low	Low	Medium	Medium
Low	Low	Low	Medium

Consequence

For critical equipment, each piece has to be studied in more detail to determine what data is possible to be collected and what fidelity (i.e. frequency and accuracy) is needed for more detailed analytics. The normal ICSS IoT sensors are a good start, but certain types of analytics will need more complex data (i.e. sounds, vibrations, thermal profiles, etc.). In some cases additional IoT sensors would be needed. A key point is that much of the data will be routine ("all normal readings, all within specified ranges") so in these cases there is no need to collect, store, or communicate numerical data from the Edge, only brief regular confirmation of its routine nature. When data starts to show deviations from expected values it needs to be captured and contextualised with simultaneous process/production data.

In some detailed systems, data needs to be collected to define what is "normal" and what might be considered part of a "failure signature" for some equipment in the process of degrading and/or failing. Fact based operational and maintenance knowledge of how equipment degrades needs to be input into the selection of analytics. Various parameters like flow rates, pressure, temperature, and vibrations will vary from normal ranges to eventually problematic ranges for several types of equipment:

- A SECE control valve might have process related erosion of valve bodies or trim components (i.e. seal ring and gasket loss; stem, body, and trim retainer wear on the seat ledge; plug, seat ring and gasket loss; or packing leakage) which can affect its ability to provide the necessary pressure and flow control through the valve. Operators need to be able to capture data showing differential pressures for these valves at each valve position (i.e. whilst opening, closing, or throttling) and the particular

[3] https://www.sageautomation.com/blog/equipment-criticality-ratings-and-why-they-are-so-crucial-to-manufacturing-maintenance

operating conditions. Over time a database of these pressures can be analysed to show how degradation in performance progresses and can be better predicted. This data may also indicate how process parameters might be adjusted to get smoother operational performance.

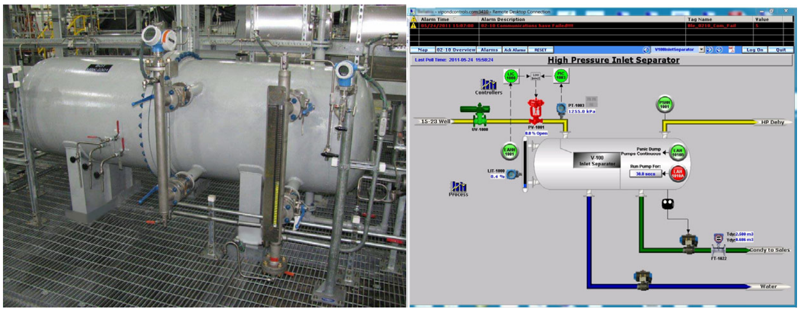
- A SECE shutoff valve will need to be able to rapidly close in a specified amount of time with a specified amount of hydraulic or pneumatic pressure on its actuator - each of these variables can be monitored during actual closure and opening, but this testing could require a shutdown or for the safety system to be disconnected during testing – neither one of these options is very attractive. Riyaz Ali from Emerson explains that "the most likely failure mode of a discrete shutoff valve is remaining stuck in its normal standby position. Testing for this type of failure requires stroking the valve only a small amount to verify it is not stuck. This partial-stroke technique can detect a large percentage of covert valve failures."[4] A typical live production, partial stroke test can be ~10% closure and then back open – the valve would use a digital positioner with position and pressure sensors, measuring valve stiction, pneumatic or hydraulic pressure required to move the valve, the speed at which the valve moves, air leaks and some other parameters. This data is transmitted through HART protocol to the Condition Monitoring system where it can be Edge processed, stored, and communicated as appropriate with field and remote users. Periodic testing would create a database able to be reviewed for any degradation with time that might require maintenance. Full closure tests should be able to be done during scheduled shutdowns which might be at longer time intervals.

[4] https://www.emerson.com/documents/automation/article-smart-positioners-in-safety-instrumented-systems-deltav-en-55906.pdf

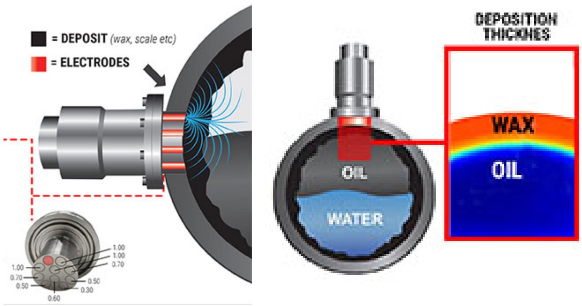
- A PCE pump might have cavitation on the pump impeller which can cause damage to the vanes or housing. Data is needed to allow timely adjustment to operating parameters including suction head, fluid temperature, and/or decreasing the net positive suction head required (NPSHr). Real time data is needed by operators to check the presence of cavitation which can be detected by vibration and sound data. The onset of other pump failure mechanisms like bearing failures can be detected with monitoring high frequency impact faults. In all these scenarios there are failure stages where advanced analytics can detect the early signs of degradation that might not normally be spotted until much later with gross failure indications – sometimes too late to do preventative maintenance or adjusting operating settings to reduce damage to prolong MTBF.

- A PCE heat exchanger responsible for cooling process fluids could have fouling which impedes flow and increases pressure drops, reducing the efficiency of the equipment and sometimes causing hardware failures (e.g. leaks). IoT instruments can measure flow and pressure drops to provide real time data of potential degradation in performance - when maintenance including backflushing should be performed and even facilitating automation. The data can be Edge processed and may not necessarily even need to be captured and communicated outside of the facility if it is part of routine operations and maintenance.

- Instruments can drift away from their initially calibrated state. This can be a problem caused by environmental contamination, vibration, or temperature fluctuations. Drift causes measurement errors with time. Previously this led to unscheduled expensive preventative maintenance, sometimes even requiring process shutdowns. One solution for critical instruments is to use dual instruments adjacent to each other with a transmitter to monitor the differential between the readings, and if the data readings drift apart more than a preset range, the data as well as an out-of-range warning or alert could be sent to the Condition Monitoring system. A more recent solution was to have a Digital Twin model producing virtual instrument readings that, assuming the model was tuned, could be used to replace some of the physical IoT instruments until such time as routine regular maintenance schedules allowed maintenance to be performed. So the data could be a mixture of physical and virtual readings.



- The deposition of scale or wax can affect flow performance which can be seen in changes in differential pressures but it can be hard to measure without opening up the process equipment or piping. A special imaging solution utilises external Industrial Process Tomography (Electric) to perform non-invasive process monitoring[5]. Again this data can be Edge processed and may not necessarily be communicated until such time as any deposition became material.



Data needs to be collected in the right fidelity if it really going to be useful. Certain electrical equipment (e.g. motor driven compressors or pumps) that use Variable Frequency Drives can have DC pulses that can cause interference through the motors and cables, damaging components and degrading machine performance. Trying to monitor these electrical voltages at less frequent time intervals to use in data analytics can miss some of this interference unless the right fidelity of data has been specified. Vibration data (e.g. gas turbines) may similarly be collected at periodic intervals for purposes of safety or control, but may not be at the frequencies needed to perform advanced analytics.

Subsurface data from downhole and surface tree IoT instruments has the benefit of being able to be directly extracted from most PI data systems since the fidelity is not as critical for production fluids from typical oil and gas reservoirs. Only the case of liquids or hydrodynamic (gas) slugging or fluctuations might require more frequent data requirements. This data is able to be compared easily with integrated dynamic simulation model results from subsurface reservoirs connected with surface facilities. With a finite number of wells in most developments, the data requirements are reasonable in terms of bandwidth requirements for communication to Cloud data platforms and remote technical users.

With data, it is really better to start "small" (i.e. SECE, PCE, and subsurface) and work your way up to "big data" – get incremental wins with data collected for these types of technical examples and be able to demonstrate the value of doing this for stakeholders. The business case for increasing the digital

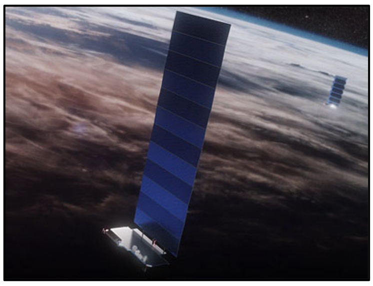
[5] https://www.rocsole.com/see-beyond#see-beyond-products-and-services-4

transformation efforts across developments will then be easier. Even equipment and systems not judged to be so critical need to be operated properly and maintained when required (i.e. predictive and preventative) and the cost to monitor these items and perform critical analytics will be cost effective. In the next section I will address the communication systems available to handle increasing amounts of data and the associated bandwidth requirements.

3. Satellite Communications for Remote Oil & Gas Facilities

At a recent technical conference, it was noted that some remote oil & gas facilities may have communication challenges to share larger amounts of data. Historically many remote facilities have had "vintage" satellite communications in the form of Very Small Aperture Terminal (VSAT) systems linked to geosynchronous (GEO) satellites with restricted bandwidths and poor latency. There is no longer any reason to accept these limitations. Costs have dropped by orders of magnitude for satellite services, hardware, and data handling. Multiple orders of magnitude service improvement is possible for essentially the same legacy cost. For modern digital transformation data flows to support IIO&P outcomes we need this capability and fortunately competition in the satellite industry is delivering it very economically. Worldwide connectivity is tremendously increasing thanks to all the various connected industries and public demand.

Satellite frequency bands include: (1) L-band (1-2 GHz) for GPS, satellite mobile phones, and Inmarsat; (2) C-band (4-8 GHz) for satellite communications including television, used in areas with heavy rainfall; (3) X-band (8-12 GHz) for military, radar applications, weather monitoring, air and sea traffic control; (4) Ku-band (12-18 GHz) for most common satellite communications; and (5) Ka-band (26-40 GHz) for general satellite communications. Each frequency band has advantages and disadvantages (i.e. bandwidth, latency, susceptibility to rain fade), and each is applicable to different satellite communication requirements including hardware (e.g. antenna type and size) and power requirements. It can be confusing without proper technical advice – but there are good communication service companies available to help.

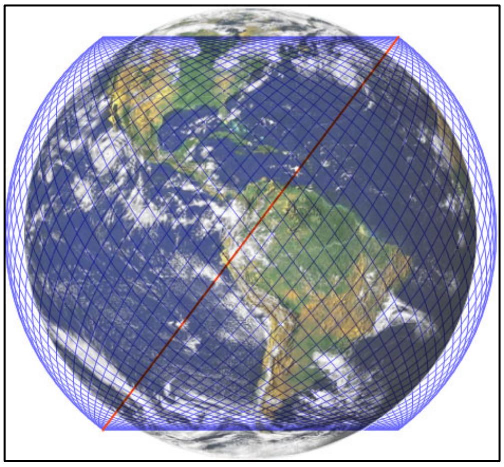

(1)

(2)

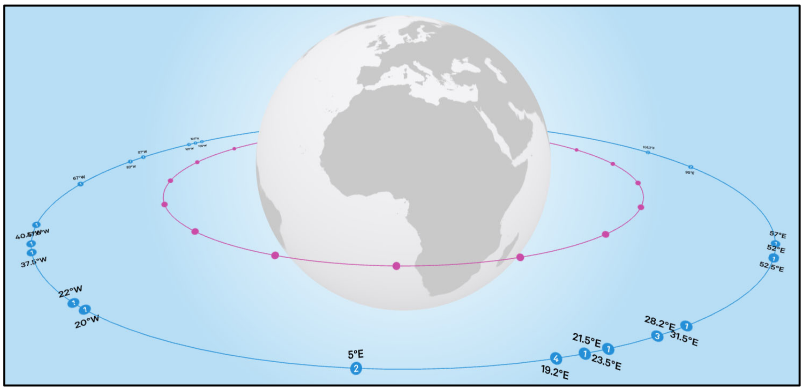
(3)

There are several types of satellites including:

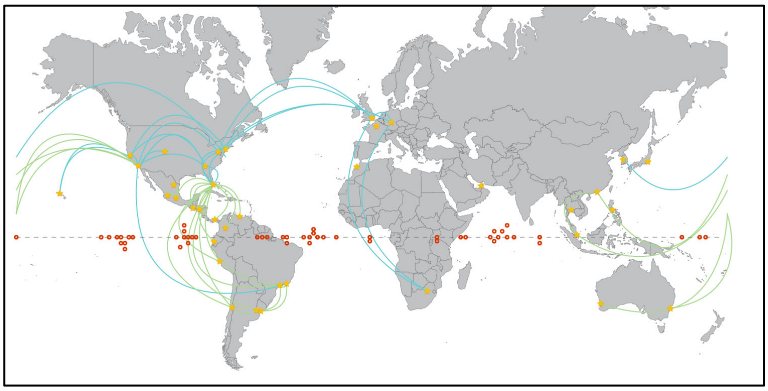
(1) Low Earth Orbit (LEO) including constellation systems like *Starlink*;



(2) Medium Earth Orbit (MEO) including constellation systems like *O3B*;



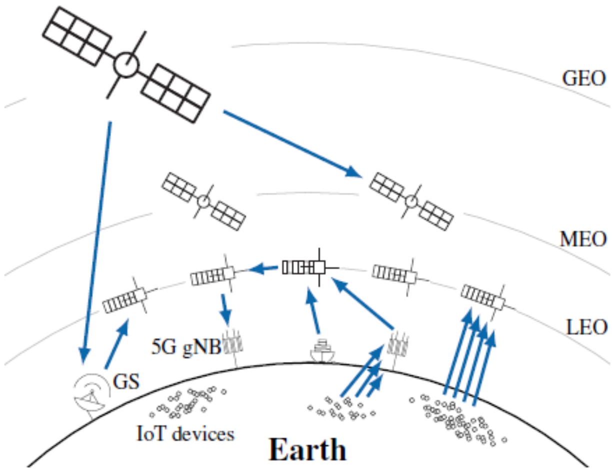
(3) High Throughput Satellites (HTS) including geosynchronous (GEO) systems like *Intelsat*.



Different satellite systems have fixed or steerable beams, widths ranging in size from 125 km (LEO) to 700km (MEO) to multiple beams providing hemispheric coverage (HTS).

With so many choices, it is recommended to not just select one satellite type with a single satellite company, but rather to contract with a satellite service provider. A service provider can provide global multi-band satellite communications platforms – the ability to switch between satellites and frequency bands as needed based on environmental conditions, geographical location, and data requirements. Individual satellite systems themselves can have issues either with the satellites or the earth stations, so redundancy in data paths is a good capability to have. It is better to contract for Data (upload and download) than to contract for a single satellite communication package.

Different satellite types combined with the various satellite band frequencies lead to user accessible bandwidths ranging from 50 Mbps up to over 1 Gbps with latencies from 280ms down to as low as 20ms. Individual beams can typically be shared, but data capability can be flexible as required and sometimes beams can be dedicated depending on the commercial arrangements. In recent years, remote FPSO developments have selected satellite communication systems with 50-100 Mbps bandwidth (compared with “vintage” systems of 6-8 Mbps) but increased bandwidth requirements are likely in the future. Edge pre-processing and analytics should be used as much as possible to help manage the bandwidth requirements for data leaving facilities. Potential IoT data feeds are increasing and video communications with remote technical teams are powerful tools to help minimise field team manning whilst giving them increased support during critical operations and maintenance. LEO and MEO satellite constellations are delivering significant potential increases in bandwidth to help meet these data handling needs.



A new communication tool for remote oil & gas facilities is linking satellite systems to terrestrial 5G networks as shown in this sketch ("5G over satellite"[6]). 5G mid-band frequency (2.4 – 4.2 GHz) wireless transmission systems with good bandwidth (100-600 Mbps) and low latency (10-20 ms) have the ability to penetrate through complex facilities but have a relatively short range (a several mile radius). Using public or private (dedicated) fixed or moving cellular base stations ("gNB" in the sketch above) acting as relay nodes, 5G data transmissions could be connected into satellite communication systems for onward transmission ("backhaul") over longer distances. There is also the possibility that some LEO satellites could eventually receive 5G transmissions. Hybrid systems could then connect LEO satellites with MEO and/or GEO (HTS) satellites. Many people are aware of 5G potential for cellular telephone systems, but using 5G connectivity for low power, low cost IoT devices ("Massive Machine Type Communications" (mMTC)) has the potential to efficiently transfer large amounts of IoT data from thousands of IoT devices in a facility or field. Jeffrey Hill-*Via Satellite* reported: "The 5G network will not be exclusive to one connectivity pipeline. The "always-on" functionality of 5G applications requires an eclectic mix of cellular, satellite, fiber, small cell antennas, microwave, modems, and processors, all weaved together in a complex, indoor and outdoor network infrastructure, which changes depending on the environment and location."[7] System developers like Charlie Ergen-*Dish/EchoStar* have led a push to spread the availability of hybrid systems connecting satellites to 5G networks in order to support these IoT applications.

The ultimate aim is to get IoT data from our remote oil & gas facilities and get it loaded onto data platforms in the Cloud where multiple users can access it. With these satellite capacities commercially available at reasonable cost, nobody should hand carry data from remote oil & gas facilities back to corporate offices or remote users except as emergency backups. Then with higher satellite bandwidths and good latency, detailed support from remote technical teams can be routinely provided to the field teams through Augmented Reality (AR) communications helping them to better operate and maintain our remote facilities. This remote support should allow reduced manning in the field, should help maintenance be performed quicker and more reliably, and should improve safety of the facilities. Modern satellite communication systems are an important tool helping to deliver the digital transformation needed for Integrated Intelligent Operations & Production.

[6] "LEO Small-Satellite Constellations for 5G and Beyond-5G Communications", B. Soret, I. Leyva-Mayorga, M. Röper, D. Wübben, B. Mattiesen, A. Dekorsy, and P. Popovski, Dec 2019, https://www.researchgate.net/publication/338003797

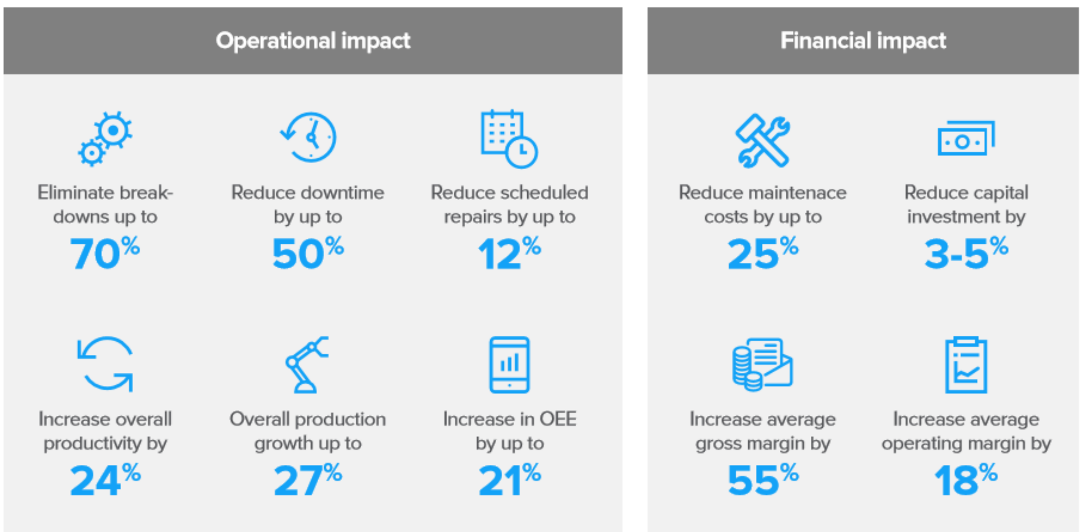
[7] http://interactive.satellitetoday.com/the-dish-on-ergens-5g-masterstroke/

4. Enterprise Asset Management and Digital Transformation

Digital transformation is in progress for many oil & gas developments and Integrated Intelligent Operations & Production is the aspirational performance outcome. How does Enterprise Asset Management (EAM) fit into this picture?

Asset management is about helping oil & gas facilities be managed throughout their life cycle "to maximize their use; save money; improve quality and efficiency; and safeguard HSE"[8]. Taking better care of assets helps reduce unplanned events that disrupt operations which defers production therefore losing revenue and value. EAM software systems cover Supply Chain, IoT, Work, Mobility, Analytics, Planning & Scheduling, Health & Safety, and Asset aspects of a wide range of industries.

There are significant positive operational and financial impacts from using digitally driven EAM[9] as shown by the graphic below:



[8] https://www.g3pconsulting.com/en/digital-transformation/enterprise-asset-management-system-eams
[9] https://pages.infor.com/eam-asset-intensive-industries-finding-the-straightest-path-to-the-cloud.html

Gartner has a good review of EAM systems from many providers[10] including (but not limited to) AVEVA *Avantis*, IBM *Maximo*, IFS *Applications*, Infor *CloudSuite EAM*, Oracle *WAM*, and SAP *EAM*. IDC has separately rated these six (6) providers as leaders in "Cloud Enabled Asset Intensive" EAM systems[11]. Each provider's EAM has different attributes which may or may not be best applicable to your particular organisation or facilities.

A very applicable subset of EAM is Asset Performance Management (APM) which IBM defines as "delivering insights at the point of action to minimize unplanned repair work, reduce equipment failure, increase asset availability and extend asset life without unnecessary costs."[12] In this section I will use the larger system acronym EAM for convenience.

EAM systems should not be considered as standalone systems with unstructured data being manually input and processed at some central corporate location. Historically some EAM systems were only used for procurement, inventory management, and then manual maintenance applications – that has now changed significantly. We have seen how contextual databases in our Cloud data platforms can be created and managed to gather life cycle data for ongoing use as required. This data can include engineering analytics, design calculations and deliverables, functional design specifications, material certificates, testing data, supplier data, and construction data. Equipment data can include traceability (raw materials and parts including all processing from source to use), vendor test and certification results, details of required life cycle surveillance and testing, recommended commissioning and operational spares, and recommended maintenance including required personnel competence, tools, and procedures. These databases can contain structured and unstructured data including audio-visual aids like vendor photographs and instructional videos for equipment operation and maintenance training.

Progressive loading of these Cloud data platform databases throughout a development's life cycle makes it easy to build a modern digitally enabled EAM system in preparation for actual field operations. We need contextual data, suitably configured and accessible to and from the EAM system with API's. These databases should be updated live with field data (operations and maintenance) to deliver best ongoing functionality.

In the field, IIO & P is about doing things better and maintenance is a key performance challenge. As we have noted previously, a significant percentage of maintenance is done at the wrong time or in the wrong way. A good aspirational maintenance system is one where a Digital Twin comparison (field data to theoretical data) has been used to identify potential performance degradation which has then been able to be verified more closely with data analytics (either on the Edge (online) or remotely (offline), possibly using Machine Learning) to look for "failure signatures". The EAM system should be configured to receive these early indicators and automatic steps should be taken to get ready for preventative (corrective) maintenance. Work orders should be automatically prepared (linked to the particular equipment or system tag number) and readiness checked against availability of (1) updated safety/risk assessment of the potential maintenance work; (2) competent field personnel trained on the work necessary; (3) tools required for the work procedures; and (4) spare parts available in the correct location (in the field or, if in a remote location, being retrieved and shipped to the field). Any gaps

[10] *"Gartner, Magic Quadrant for Enterprise Asset Management Software", Kristian Steenstrup, Nicole Foust, 14 October 2019*

[11] *IDC MarketScape Worldwide SaaS and Cloud-Enabled Asset-Intensive EAM Applications Vendor Assessment, March 2019*

[12] https://www.ibm.com/internet-of-things/solutions/enterprise-asset-management/asset-performance-management

should be resolved by the EAM system automatically generating work orders for the necessary preparations to be performed by field or remote support teams (i.e. engineers, supply chain / logistics personnel, operators, or maintenance technicians). Safety/risk assessments could be ordered to be prepared and loaded into the system. Competent personnel could be sourced / assigned / mobilised or in some cases trained online (e.g. refresher training with VR systems inside the Cloud data platform). Tools and/or spare parts could be located and mobilised by logistical teams to be in position in the field ready for use.

After the necessary pre-clearances, work tickets should be automatically readied within the EAM system for issuance to and use by the field team to make final checks prior to performing the maintenance work – a key requirement is isolation of the equipment from hydrocarbons or energy (power or pressure). The EAM system should check the Cloud data platform for the particularly tag number to check that the equipment has been inactivated, isolated, and made safe (e.g. depressured) ready for maintenance (potentially checking against live ICSS or PI data for example). From industry experience, maintenance has been unsuccessful when some of these pre-clearances were not really ready. With systematic (i.e. automatic, routine, regular, and predictable) procedures set up inside a Cloud data platform linked EAM system, the field teams should be better prepared to perform maintenance at the right time, working productively and effectively to complete work correctly the first time attempted.

As a digitally driven EAM system matures, reliability data should be collected and stored from maintenance activities. Equipment failures (or failure signatures) should be tracked to determine whether other similar equipment (i.e. from the same suppliers, with similar operational functionality, or exposed to similar potential failure risks) may require closer automatic monitoring or changes in integrity operating windows to help mitigate potential failures. Other data including mean-time-between-failure and mean-time-to-repair should be collected and automatically monitored to see if operational or logistical changes were needed. Databases of "standard, repeatable jobs with automatic work order generation based on any combination of user-defined triggering criteria such as operating statistics, elapsed time, and calendar date, as well as inspection checklists and preventative maintenance" should be prepared inside a good EAM system[13]. Inventory management is a common challenge – what spares, kept where, how ordered / reordered, and how actually made available in the field to maintenance technicians – and the EAM system needs to facilitate better responses to this challenge by tracking statistics and data of actual field availability of spares and specialty tools.

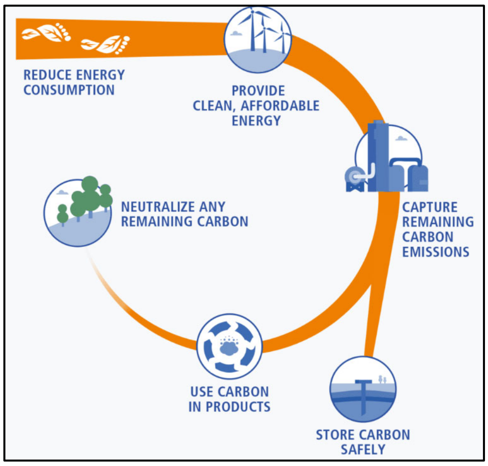
Digital transformation enabled Enterprise Asset Management software systems are an important part of delivering Integrated Intelligent Operations & Production for oil & gas developments. Significant potential value is at stake. In order to realise this value however, cultural changes and work flow changes will also be needed to improve the delivery of data-driven insights and decisions.

[13] https://sw.aveva.com/asset-performance/asset-maintenance/enterprise-asset-management

5. Digital Transformation and the Energy Transition

An important consideration for existing oil & gas assets and prospective new developments is whether this industry can effectively support the Energy Transition. The term Energy Transition has been defined as including improvements in energy efficiency, reduction of carbon footprints, and movement to more sustainable sources of clean energy. Different stakeholders focus on different parts of this transition. Obviously this is a topic with a wide range of views, but the purpose of this document is not to espouse any one view, but rather to demonstrate how Digital Transformation can help make positive incremental improvements throughout the transition. The Energy Transition will continue to increase in importance as the investment community raises the prioritisation of environmental, social and governance (ESG) factors. The ability of oil & gas companies to demonstrate incremental Energy Transition improvements will be essential to support continued investment, improve access to funding / finance, and maintain support from shareholders and other stakeholders.

A group of twelve (12) large oil & gas companies representing ~32% of upstream energy production formed the Oil and Gas Climate Initiative[14] and they represent an industry perspective on Energy Transition. In addition to internal and cooperative progress towards Energy Transition, they are investing in third party technologies and R&D to facilitate the drive towards low carbon and Digital Transformation is involved.



Three of OGCI's objectives are as follows: (1) reduce methane emissions; (2) reduce CO_2 emissions; and (3) recycle and store CO_2. Reducing methane emissions during production, delivery, and use of oil and gas could involve more efficient processing and transportation such as minimising any leaks (including fugitive emissions) and eliminating flaring. Reducing CO_2 emissions could involve cleaner combustion and reducing unnecessary operations and logistics. Recycling and storing CO_2 could involve isolating sources of CO_2 so that it could be captured, stored, transported, and reinjected downhole into depleted reservoirs or aquifers. Digital transformation has a good potential role facilitating each of these objectives.

According to UN Environment Programme[15], methane is over 80 times more powerful than carbon dioxide as a warming gas over a twenty-year timeframe. The oil & gas industry is estimated to be responsible for up to 25% of anthropogenic methane emissions. International Energy Agency data was

[14] https://oilandgasclimateinitiative.com/
[15] https://www.unenvironment.org/news-and-stories/story/homing-methane-emissions-oil-and-gas-industry

used in a report[16] that estimates ~3-4 TCF of natural gas escapes each year with the majority being methane – this is significant lost value which should offset costs to reduce these losses. Government regulators are becoming directive, requiring actions including monitoring and reporting reductions. Reducing methane emissions could be facilitated by (1) better remote IoT device (including existing sensors) monitoring and diagnostics; (2) Digital Twin comparisons of actual IoT data to theoretical data (from dynamic simulation models) to see where processes may be suboptimal; and (3) adjustment of operating settings to ensure equipment is in the best integrity operating windows. Poorly maintained equipment has increased risk to fail (e.g. seals) or leak so better predictive and preventative maintenance based on data analytics will help reduce methane leaks and reduce any lost production.

Unnecessary operations can include reducing the number of wells drilled and facilities required whilst maintaining the same or increased levels of production. More efficient drill rigs using digital transformation tools and procedures can drill wells quicker (more efficiently, with less unproductive time) thereby reducing the number of rigs required. Subsurface data gathered during exploration and appraisal drilling can be transferred into geological models and dynamic reservoir simulations to plan development wells and resource recovery plans. Integrated reservoir modelling combined with surface facilities modelling allows optimisation of overall systems to further increase recoveries. This means a reduction in well numbers with more production (estimated up to additional 6-8%) from reservoirs. Across a portfolio of assets, this should result in a lower carbon footprint.

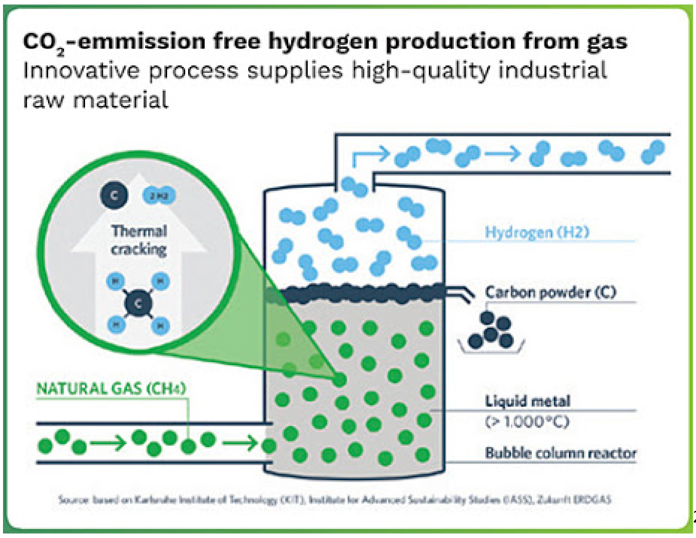
Recycling and storing CO_2 can have the obvious environmental benefit of reducing CO_2 emissions, and for certain reservoirs the CO_2 can also potentially support Enhanced Oil Recovery (EOR)[17]. EOR increases production due to the miscibility of CO_2 with the oil which reduces viscosity and provides a displacement flood helping to sweep the oil. Using real time data from subsurface and surface IoT devices fed back in a timely manner to subsurface teams for their integrated reservoir models would facilitate adjustments to the amounts and locations of CO_2 injections to optimise overall field production whilst maximising the amount of CO_2 sequestered.

The final step in Energy Transition is moving to more sustainable sources of clean energy. Hydrogen is an attractive source of energy that can be produced from natural gas in a process called "blue hydrogen" which involves thermal processes such as steam-methane reformation[18] to support near-term hydrogen production. CO_2 is produced in this process, so to be more sustainable, the CO_2 needs to be captured, stored, and reinjected downhole (sequestered). Peter Coleman-Woodside has stated "Blue hydrogen is the key to building scale and lowering costs in hydrogen transport and distribution, which will enable an earlier transition to renewable green hydrogen, produced through electrolysis of water, powered by renewables. The earlier we can shift, the faster we can reduce emissions."

There is also a clean process of hydrogen production from methane called pyrolysis which is being developed now[19][20]. Natural gas is heated up to high temperatures in order to generate hydrogen and the only residue left is carbon in a solid form which can be used as a valuable ingredient in several industrial processes. Pyrolysis is cheaper and more scalable than electrolysis and since sequestration of CO_2 is not required, it can be cheaper than blue hydrogen. So the oil & gas industry can participate in

[16] http://rhg.com/wp-content/uploads/2015/04/RHG_UntappedPotential_April2015.pdf
[17] https://www.netl.doe.gov/sites/default/files/netl-file/CO2_EOR_Primer.pdf
[18] https://www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming
[19] https://www.iass-potsdam.de/en/news/zero-emission-hydrogen-production-natural-gas-german-gas-industry-awards-prize-researchers
[20] https://www.nature.com/articles/s41929-019-0416-2

the transition to hydrogen as one source of clean energy. Digital transformation would be involved to ensure these processes were safe, efficient, and economically sustainable.



[21]

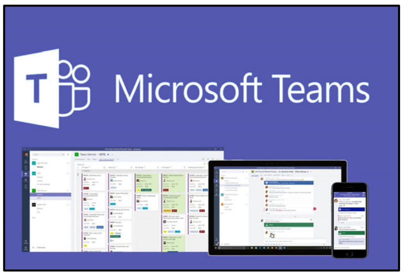
The IEA has stated "The lack of technological innovations to detect emissions and deliver reliable measurements at low cost is a key technology gap that needs to be a focus of both public support and private initiatives. Methane management can also be embedded in the oil and gas industry's ongoing digitalisation efforts."[22] We have the technology, we have the tools, and we understand what needs to be done; now we just have to execute to support the Energy Transition, helping the environment as well as being a more sustainable, fundable industry.

[21] http://www.europeanenergyinnovation.eu/Latest-Research/Spring-2019/KITT-IASS-Producing-CO2-free-hydrogen-from-natural-gas-for-energy-usage

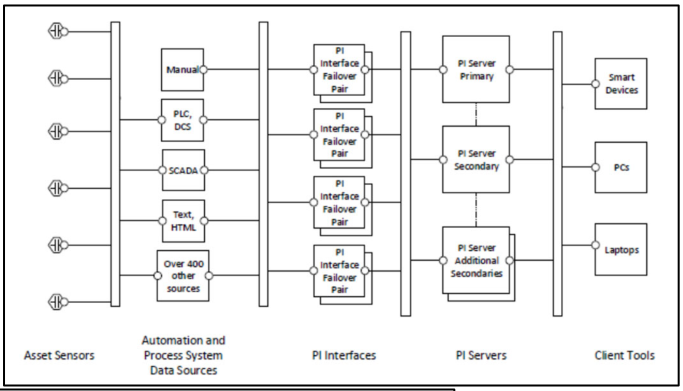
[22] https://www.iea.org/reports/tracking-fuel-supply-2019/methane-emissions-from-oil-and-gas

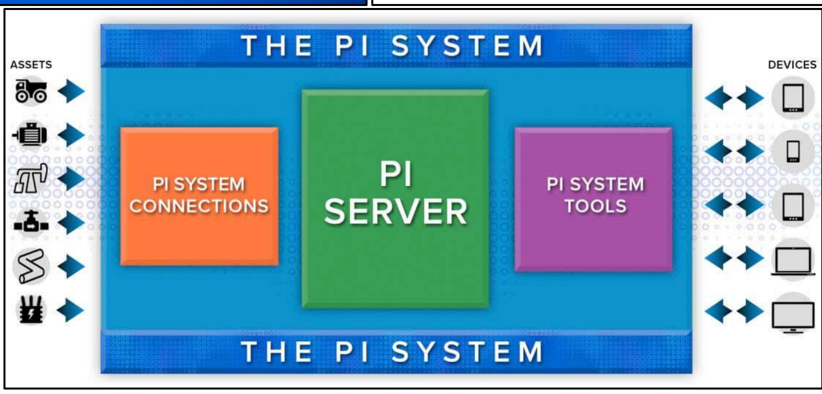
6. Remote Working and Unmanned Facilities

Public health considerations mean that there is an increased focus on and familiarity with the concept of remote working. All over the world people have discovered that they can perform a lot of their company work at home. Computers with webcams using Microsoft Teams or video conferencing apps like Zoom have shown how people can be connected and work together remotely. Shared desktops and drives with these software systems have demonstrated the ability to share data quickly and efficiently among remote workers. “Working from Home” where possible is helping to keep companies working through public health challenges and it is likely a precursor of modified work procedures in the future for some companies.



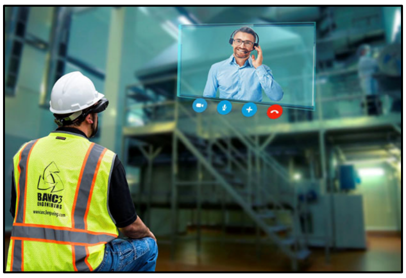

It is not that difficult to extend these concepts to remote working with unmanned facilities. Existing operational intelligence and analytics systems like *OSIsoft PI* “collect, analyze, visualize and share large amounts of high-fidelity, time-series data from multiple sources to people and systems across all operations.” These systems are being extended across industry facilities infrastructure connecting IoT data through facility ICSS systems to multi-Cloud Data Platforms to on-premise Enterprise Data systems, allowing inputs and outputs to be connected to remote users located anywhere. These data flows are essential, ensuring remote unmanned facilities are operating safety and supporting asset integrity management efforts including scheduling field maintenance as needed.





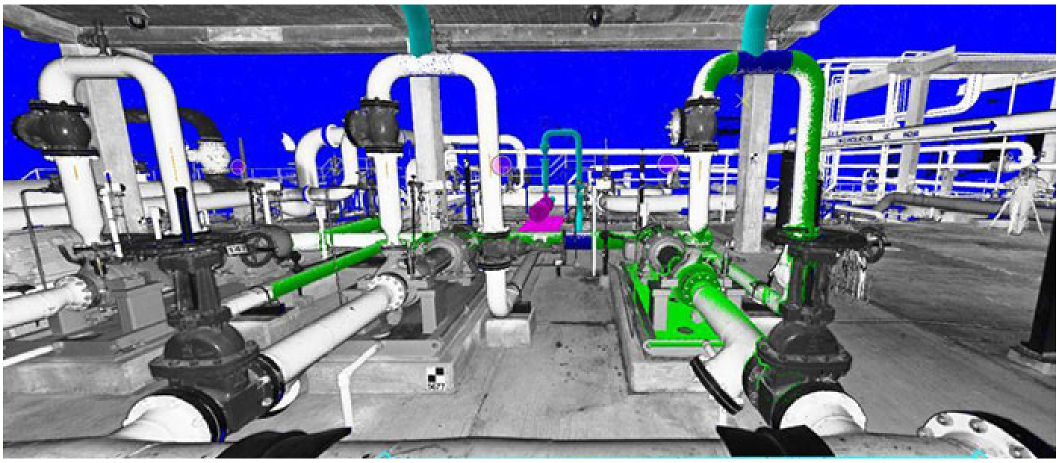
Remote monitoring, remote diagnostics, and data analytics are a key feature of these data flows. Field IoT instruments/sensors and other devices are able to transmit as much data as we have bandwidth. IoT devices capture information ranging from structured (e.g. digital instrument readings) to unstructured (e.g. audio-visual/infrared images). Practically everything that a field worker could observe and record is now possible to be captured. The need to have field workers is reduced, which improves technical safety and reduces costs. Field workers should only be exposed to the risks of remote facilities when needed to perform complex preventative maintenance activities.

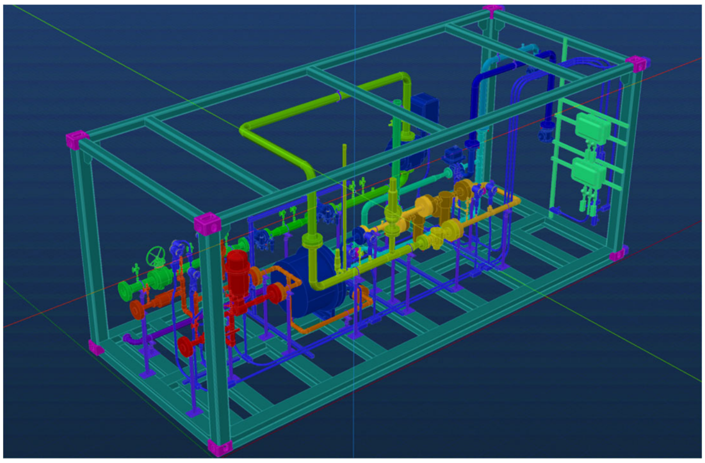
The challenge is to ensure all this data is contextualised, cleaned, and accessible for multiple users. Detailed 3D models are used with contextually linked databases from engineering to procurement to construction to operations. Field operations would then add significant amounts of operational and maintenance data. Edge computing has allowed more online analytics and pre-processing to occur in the field with corresponding improvements in bandwidth utilisation. Many of these data systems already exist and we are focussing on better use of the data.

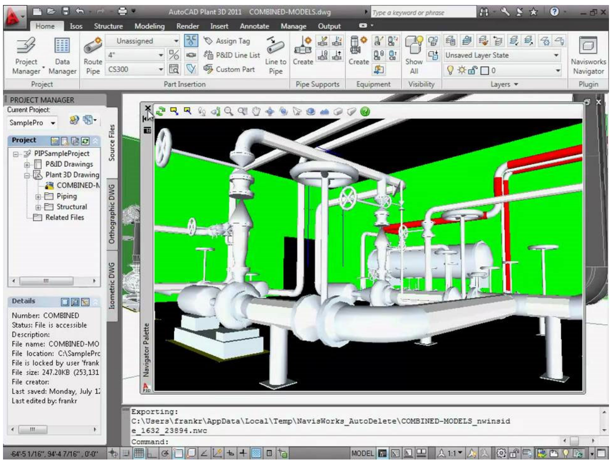




Virtual and augmented reality are key tools to facilitate working in our facilities. Virtual reality has been used to train field operators and maintenance teams to prepare for work in the field. Once in the field, support can be provided through augmented reality tools where remote technical experts can provide assistance to the field workers. Taking this a step further, there are fewer reasons to actually have people in these remote facilities if we have been planning appropriately in earlier development phases. Virtual "rounds" are possible during operations with the operators working remotely away from the unmanned facilities. Some maintenance is possible with robotic tools.

At the start of a potential development, work selecting the concept needs to focus on minimising the eventual need for field personnel. Designing for reliability (e.g. MTBF), ease of operations (e.g. flexible ICSS), and eventual ease of maintenance (e.g. "plug and play") with the best selection and specification of equipment is required. Dynamic simulations of process and mechanical operations should be used to check these equipment selections to identify integrity operating windows to extend maintenance intervals. IoT sensors should be specified to gather information needed by remote operators and data analytics. A mixture of online Edge analytics and offline Cloud analytics should be selected to improve the bandwidth requirements whilst facilitating the best timing of insights by remote operations personnel. Using a Digital Twin during design and testing, a well configured ICSS should incorporate autonomous responses to help reduce interventions required by operators. The autonomous responses can also be updated through Machine Learning results and AI agents. The ability of a ICSS system to "learn" and get more efficient is an important feature. For example, some valves need to be actuated to open or close with a certain time interval after a series of control decisions are made so that there is not an undesirable pressure surge.



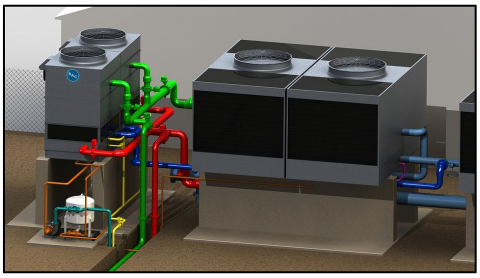
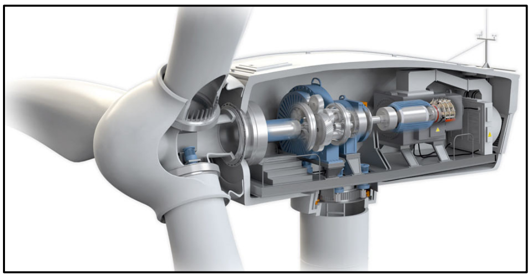
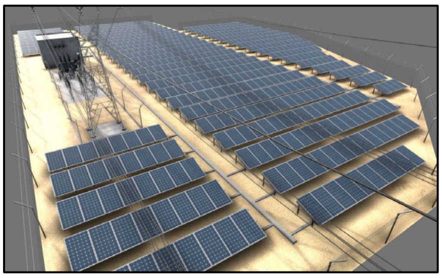




Virtual field “rounds” can be made with the help of 3D models (i.e. digital photogrammetry, LIDAR, or infrared scanned point clouds or derived from CAD models). Remote personnel can “walk” through a 3D model using VR headsets and can select and review linked contextual data for any equipment including real time operational data (i.e. pressures, temperatures, speeds, volumes, or vibrations) from ICSS or PI systems. Contextually linked data analytics can identify equipment operating within their integrity operating windows but also report equipment operating anomalously which may require intervention. With the use of distributed cameras and microphones around a facility, remote personnel can switch from virtual images to live visual or infrared images to investigate conditions within the unmanned facility. A very rigorous facility inspection can effectively be made around a remote unmanned facility by an operator located on the other side of the world. Video (visual / infrared) and audio/vibration analytics can also be set to monitor for anomalies (i.e. things moving that were not supposed to move, abnormal surface temperatures (hot or cold), or sounds / vibrations outside of normal expectations) and send alert notifications to remote operators who could then perform ad-hoc virtual investigations or inspections.

As described previously, robotics are increasing becoming a valuable tool for these remote facilities. Robotics can be fixed in one location (e.g. robotic manipulator arm adjacent to a piece of equipment with multiple manual intervention interfaces) or they can be mobile. A mobile robot (e.g. Total's sponsored *ARGONAUT* robot) could move around a remote unmanned facility providing real-time visualisation but also the ability to do some robotic interventions. Imagine a large unmanned facility with hundreds of manual valves which need to be periodically cycled or incrementally moved ("exercised") to ensure they do not seize up. A mobile robot, either autonomously or with remote direction, can move around the unmanned facility performing preventative maintenance activities. Similarly "plug and play" maintenance activities may be able to be performed by robots including activities like replacing batteries in wireless sensors. Chemicals or lubricants could be refilled into local reservoirs where there are not distributed systems. Filters may be able to be replaced by robots. Routine manual activities are increasingly able to be performed by robotic tools so that the facility can remain unmanned except for planned campaigns.

A wide range of facilities can be unmanned with remote operators. Process plants, distributed power plants, wind farms, and solar power arrays can all be unmanned and operated remotely with some routine maintenance possible as well. Responding to economic and technical safety challenges (and even public health issues), we have the ability to operate safe unmanned facilities with the help of digital transformation tools and work processes – Integrated Intelligent Operations and Production.

7. Visualisation Tools for Remote Working

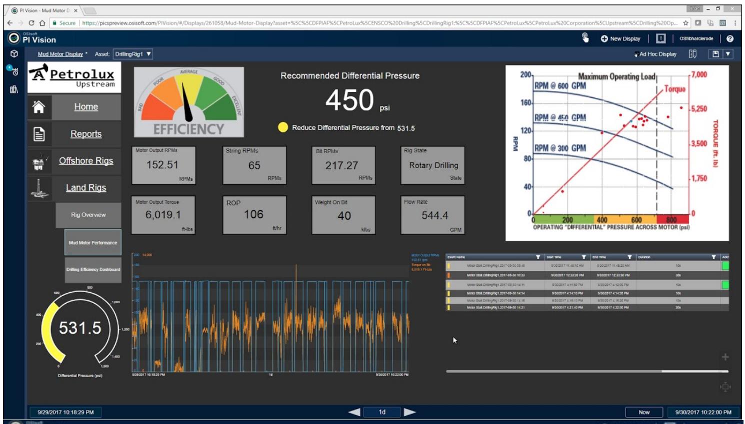
Remote working with unmanned facilities was reviewed in the last section. Key tools for remote working are visualisation of facility data as well as visualisation of the physical facility itself. We have many tools for visualisation thanks to the tremendous growth of technology and applications. Data visualisation can range from dashboards to heat maps to analytics results to system reports. Interactive visual representations have been particularly useful. The physical facilities themselves are able to be "viewed" with several types of IoT devices including video cameras, infrared cameras, microwave sensors (motion), short range radar (24GHz SRR), and/or LIDAR (laser) sensors. Industry experience has shown that a multi-layered sensor solution may offer the best operational flexibility. All visualisation tools will make use of structured (e.g. data analytics) and unstructured (e.g. images) data that needs to be processed and made available to users quickly and easily in order to make best use of the data.

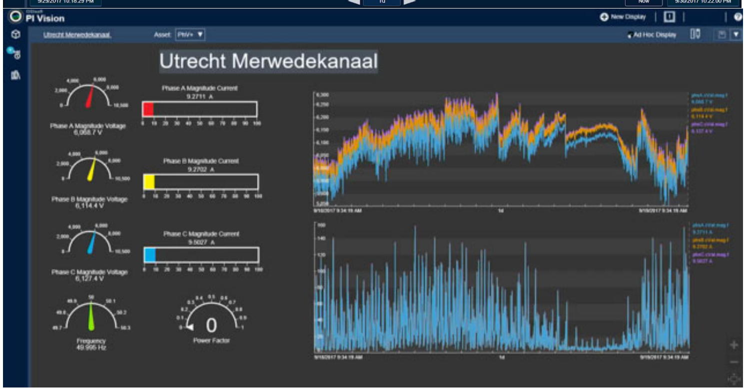
[23]

Big Data from thousands of IoT field devices could be presented on terminal screens or in printouts and charts; but there needs to be a better way to visualise it to make more sense quicker to users – this has probably been one reason why McKinsey says that ~99% of field data has not been historically used. High quality visualisation tools are needed to present Big Data in more intuitive ways. Data visualisation has a taxonomy that ranges from (1) 1D/Linear (e.g. lists); (2) 2D/Planar (e.g. geospatial); (3) 3D/Volumetric (e.g. 3D CAD models); (4) Temporal (e.g. schedules); (5) nD/Multidimensional (e.g. statistical and charting); (6) Hierarchical (e.g. trees); and (7) Network (e.g. matrices)[24]. "Data visualization is the practice of translating information into a visual context, such as a map or graph, to make data easier for the human brain to understand and pull insights from. The main goal of data visualization is to make it easier to identify

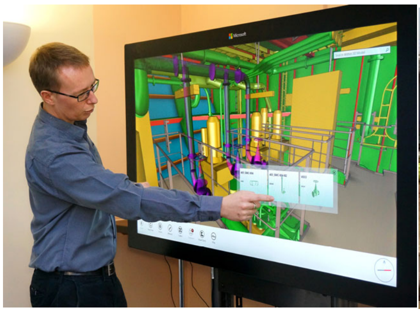
[23] "Visualization, Interpretation and Descriptive Big Data Science", M. Grandjean (2014), Les Cahiers du Numérique 10 (3)
[24] B. Shneiderman, "The eyes have it: A task by data type taxonomy for information visualizations", IEEE 1996

patterns, trends and outliers in large data sets"[25]. Two examples of operational data analytic visualisations from the *OSIsoft PI* system are shown below:



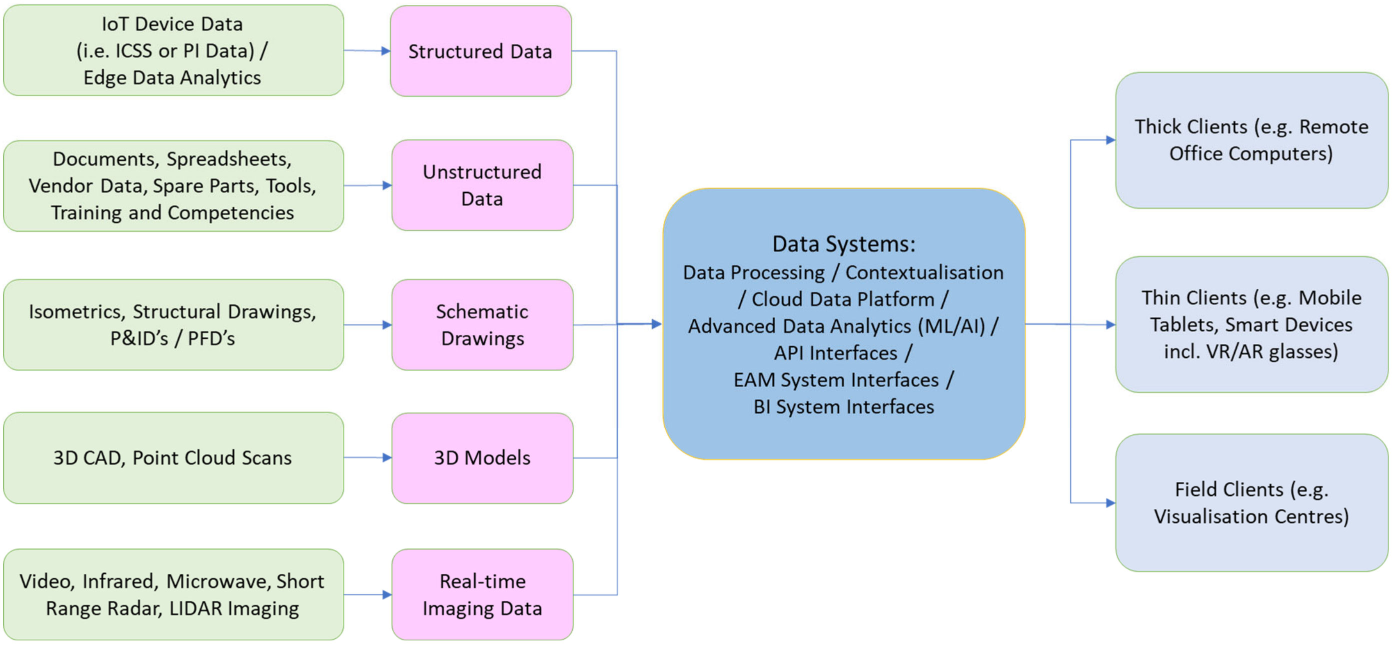


Data visualisation systems need to be flexible to provide the information to different types of users on a variety of devices (i.e. "thick or thin, mobile or stationary clients"). They might be remote technical teams in an office with large touchscreens (e.g. *Microsoft Surface Hub*), or field maintenance campaign teams around a visualisation centre (e.g. *InTouch INDT550 Touch Screen*) getting prepared to perform field work (e.g. work permits / pre-job hazard (safety) assessments), or individual maintenance workers in the field with handheld tablets (e.g. *Schneider Electric Vijeo 360*) actually performing the work. For remote monitoring or diagnostics work associated with an unmanned facility, these systems would be utilised by the remote technical teams to check the facility prior to any intervention such as changes to ICSS or operational settings. Unmanned facilities would usually have scheduled maintenance campaigns which might be the only time that personnel are mobilised to the field to perform work and it would therefore be even more important to constantly check integrity operating windows for safety / environmental and production critical equipment. We want to be able to adjust operational settings to extend maintenance intervals as safely as possible to fit with these less frequent maintenance visits.



[25] M. Rouse, https://searchbusinessanalytics.techtarget.com/definition/data-visualization

Contextual data is an underlying key requirement whether it is real-time data or historical data, structured or unstructured. For our unmanned facilities, the remote user needs to be able to access all this information quickly and easily in order to reliably perform a virtual "round" as described in the previous section. Remote operators need to have confidence that, with these data tools, they are having the best "view" of the facility and operating conditions to continue to safely and efficiently keep running.

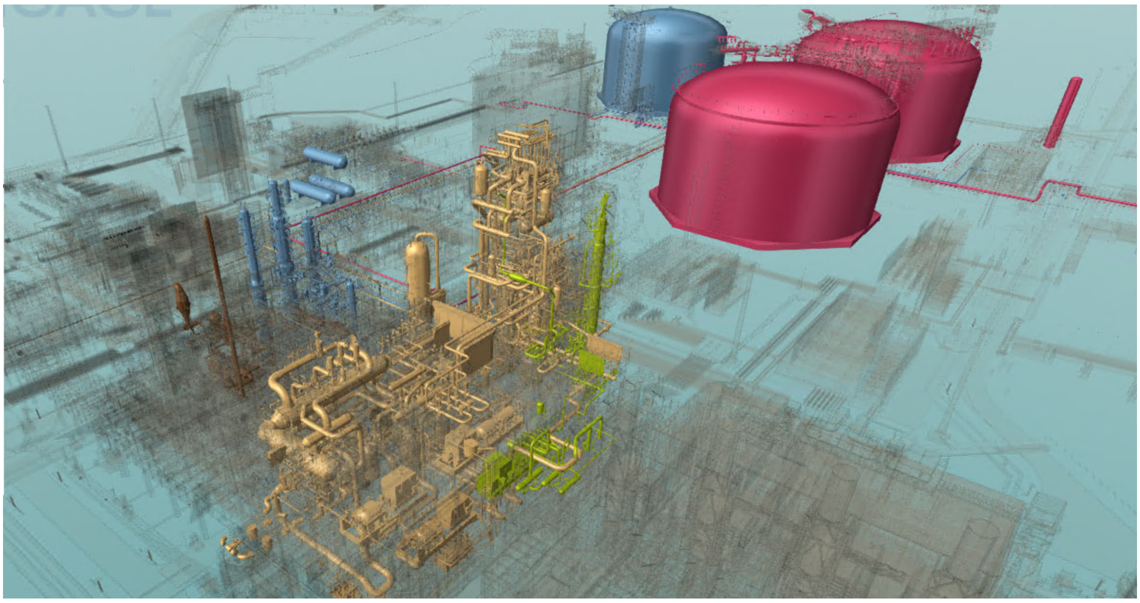


A lot of this underlying visualisation support data needs to have been prepared well in advance, starting during engineering design, through the procurement and supply process, during construction (pre-commissioning and commissioning), and up to start-up. Part of asset integrity management is knowing what is "normal" and what is anomalous – in other words, recognising when performance (or integrity) is degrading due to the condition of our equipment and systems (which also might be caused by how the facility is being operated). For remote operators, this knowledge should come from some combination of numerical and imaging data. It is essential to design, specify, configure, and construct our facilities to support the capture and flow of all applicable data, in the right fidelity, to these remote operators.

Significant amounts of engineering data from analytics to design calculations is typically prepared and sometimes just filed away in reports or masses of electronic files – often unstructured and not readily linked (through metadata) for subsequent access by operational phase users. During the procurement and manufacturing process, additional significant data is produced by all the vendors and suppliers. Every piece of equipment has (or could have) drawings, test results, operating and maintenance instructions, photographs, videos of how to install / operate / maintain, and details of spares and tools required to remove and replace equipment components. Again this information is often filed away and not as readily accessible to users during operations and maintenance. During the construction phase, every piece of equipment and length of pipework and cabling is inspected and signed off. This inspection process is an invaluable opportunity to capture observations, photographs and/or video recordings of the physical details and condition prior to field operations[26]. Later remote inspections will need to be able to determine if the physical condition of equipment, piping, or cabling is unchanged or under some process of degradation that may need further observation or even intervention. During early operations, recordings could also be made by thermal imaging devices of pipework covered by insulation in order to prepare for

[26] http://www.3mw.no/raster/plant-integrity/

subsequent Corrosion Under Insulation (CUI) surveys[27]. Equinor has used these tools at a very large LNG facility and successfully reduced manning:



(Ref. 3MW Integrity AS, Hammerfest LNG – EPIC / UAK Pilot Project, geocoded RASTER Data (tag/equipment/maintenance history/IoT conditions/documentation) within 3D Digital Twin models, winner Equinor CIU Challenge[28])

We have the technologies and tools to work remotely with unmanned facilities. As with other elements of digital transformation, success does require cultural changes and revised workflows. Preparation should start early in a facility development's engineering phase, since significant data prior to field operations is created, and we are just trying to make it more readily accessible and improve visualisation to help identify insights from the data and thereby make better decisions to increase safety and value. With modern ICSS systems and existing IoT devices, a lot of capability can also be added to existing facilities to help reduce manning and at the same time improve safety.

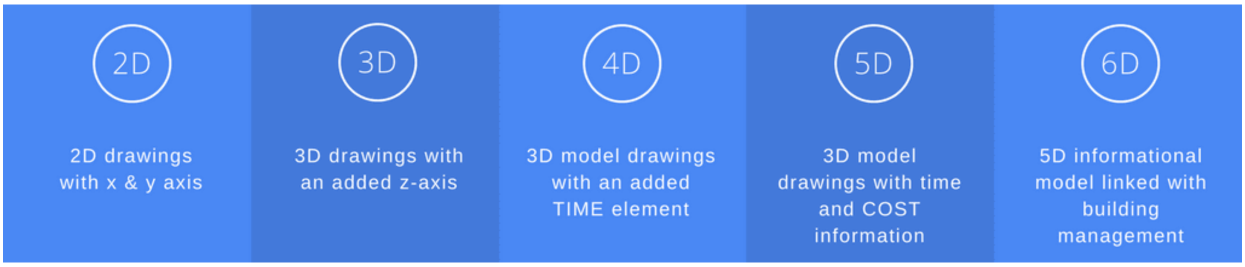
Remote control rooms of unmanned facilities could look like this Aker BP *Ivar Aasen* onshore control room, located several hundred kilometers from the offshore platform, which has been controlling the remote facility for the past year.

[27] https://www.pixelthermographics.co.uk/specialist-surveys/corrosion-under-insulation-inspection
[28] https://www.equinor.com/en/how-and-why/innovate/winner-announcement-for-cui-challenge.html

8. Risk Visualisation for Remote Facilities

Remote working with data and physical facility visualisation for unmanned facilities was reviewed in the last two sections. A good challenge for any facility, whether remote unmanned or not, is how asset and operating teams are able to visualise risk. Digital transformation provides good tools to help with visualising risk. An example from the building industry can help us identify how contextual operational data can help us manage risk in our facilities.

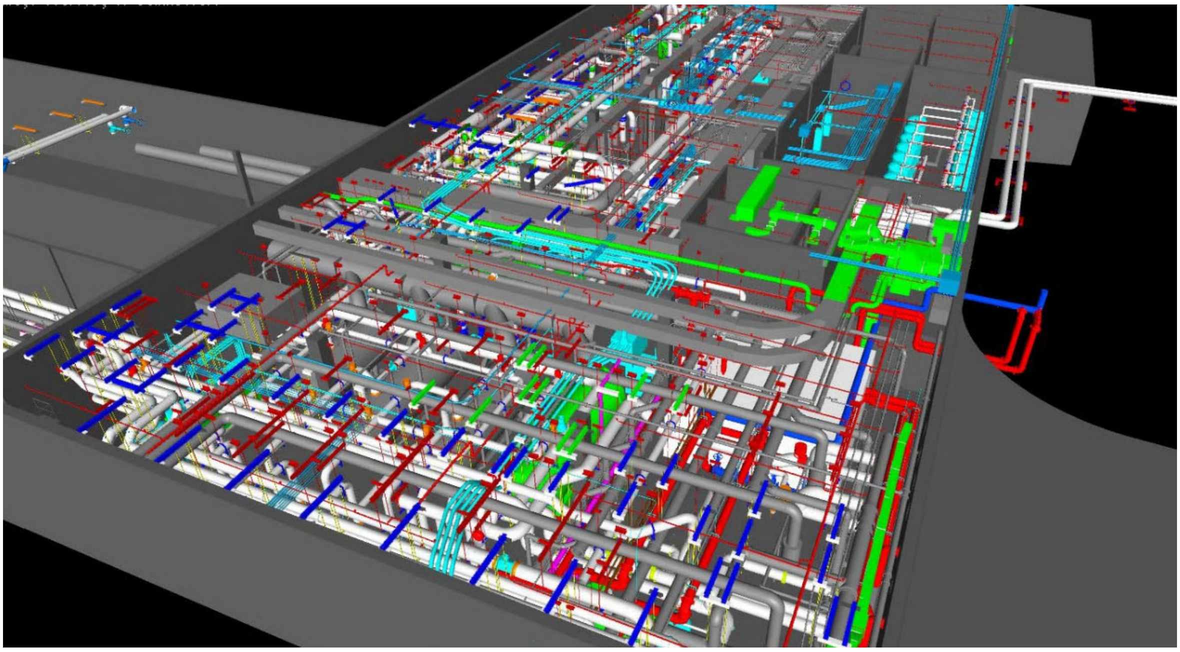
Building Information Modelling (BIM) is a well established tool for buildings and other facilities. During a facility's life cycle, a Project Information Model (PIM) is developed through the various stage gate processes from Concept Select through Define and Execution (Design, Procurement, and Construction) to handover to Operations where the model is then called an Asset Information Model (AIM). These BIM models are graphical models which have added non-graphical data and documentation in a Common Data Environment. The first six phases of BIM are as follows:



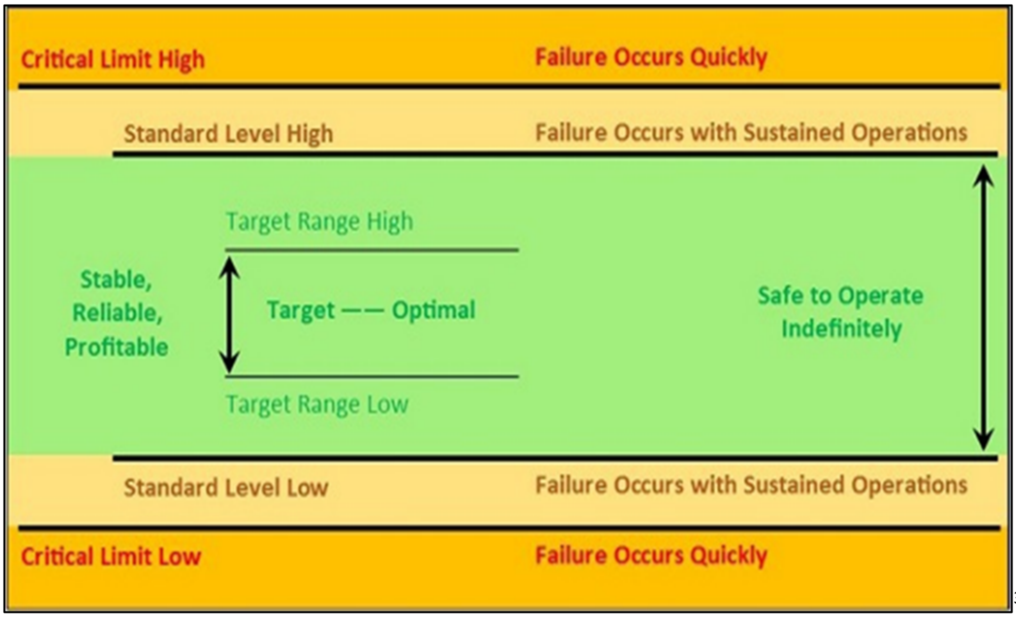
6D BIM is particularly applicable to the operation of facilities and it makes uses of contextual data gathered over the course of a development up to and including operations[29] – this concept is similar to the Digital Twin models we have been discussing over the past year. 6D BIM information can be visualised in a similar manner to 4D BIM (time/schedule) and 5D BIM (cost) where "heat maps" are used to illustrate critical tagged items (or facility components) running behind schedule or over budget. In the case of 6D BIM, the information or data being visualised can be a variety of performance data ranging from current operating conditions (i.e. on/off/live/standby, pressure, temperature, flow rate, speed, voltage, frequency, etc.) to processed data (i.e. status within integrity operating windows, whether effectively isolated (e.g. energy or pressure), or results of data analytics). For the purpose of this section, I want to focus on the use of this 6D BIM tool to help visualise risk.

One of the advantages of BIM visualisation is the ability to view data in 3D using heat maps. The underlying contextualised 3D CAD model is able to utilise software defined filters to graphically colour code the tagged items based on whatever underlying data/parameters have been identified to be visualised. A colour gradient could be used to reflect the particular data/parameter (i.e. bright red to dark blue to light blue to bright green in the graphic following). The gradient numerical values could range from negative to positive or from low to high, whatever context was desired for the particular data being visualised. This would allow a user to quickly scan the heat map and identify any significant potential performance risk issue areas, such as tagged equipment running at the edge of their integrity operating windows (or worse outside these windows). The 3D CAD facility model could show these colour codings, enabling users to quickly identify any potential issues and concentrate their efforts to examine and if needed to rectify any issues :

[29] BSI PAS-1192-3:2014 "Specification for information management for the operational phase of assets using building information modelling"

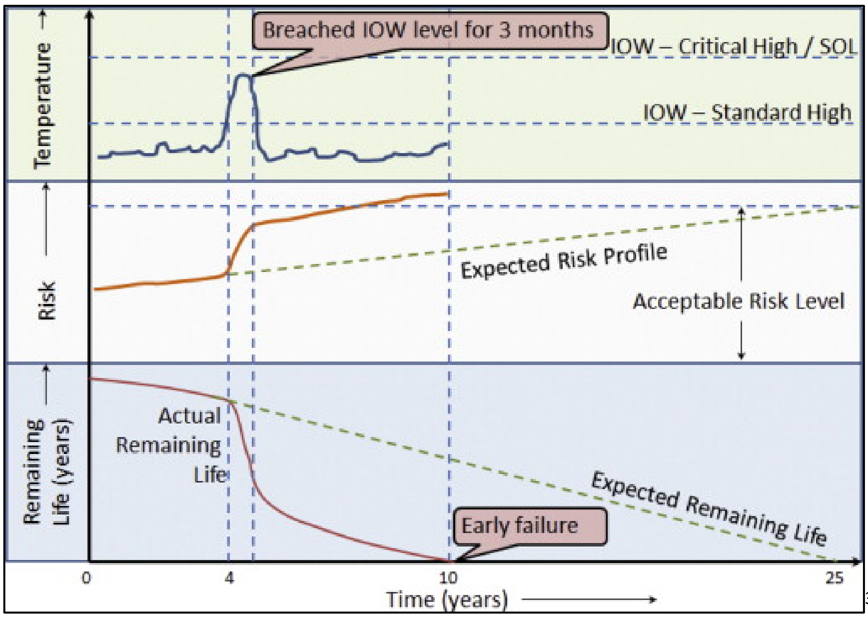


Heat mapping tagged equipment items according to how they are performing with respect to their integrity operating windows (IOW) can be a way of visualising contributing factors to the risk profiles of the particular items. But quantifying risk is complicated and can be composed of several independent factors related to the equipment itself as well as surrounding systems. Staying within an IOW (which itself is usually composed of several parameters) is an important factor however and should be part of risk scoring. Other data/parameters could be just as important in risk scoring. Any data/parameter gradient could be visualised across the larger facility as part of a BIM type 3D CAD heat map (i.e. stress, fatigue, vibrations, temperatures/thermal imaging, electrical loads, audio, etc.) to help identify, calculate, and understand the risks.



[30]

[30] API RP 584 “Integrity Operating Windows”



[31]

The purpose of this document is not to do a deep dive into risk management itself, but a key part of effective risk management is monitoring and verification. This means monitoring performance data and making use of it to characterise risks and verifying they are being managed appropriately. Two international standards are available to help manage performance requirements for operation and maintenance risk reduction measures (applied to facility equipment) including engineering controls – guards / control functions / devices and administrative controls:

(1) ANSI B11.19-2019 "Performance Requirements for Risk Reduction Measures: Safeguarding and other Means of Reducing Risk"; and
(2) ISO 13849-1:2015 "Safety of machinery — Safety-related parts of control systems.

"If used correctly, the ANSI B11 table for risk scoring of a machine, and the ISO 13849 chart for risk scoring of a control system, can help identify hazards and increase machine safety in any industrial environment"[32].

Data analytics can help prepare a "risk level score" based on parametric data received from IoT devices and/or analytic data from Digital Twin models. The highest priority equipment to be properly managed must be Safety and Environment Critical Equipment (SECE) which are required to preserve the necessary safety and control within a facility. SECE impairment can required limitations of operations or even suspension (and would be covered in most Safety Cases and operational procedures). The next highest priority equipment to be properly managed should be Production Critical Equipment (PCE) which is equipment necessary to continue production (and therefore value). Another critical input should be Asset Integrity Management performance – which involves whether maintenance is being performed expeditiously or not (e.g. are there unfulfilled (overdue) critical maintenance tickets or corrective actions). The facility's Maintenance Management System (within an EAM or APM) should be tracking these actions and contextualised compliance data should be available to be able to be accessed (from a linked Cloud Data Platform) and visualised within a BIM type 3D CAD heat map.

Other data able to be visualised to help form a better picture of a facility's risk profile could include the following: (1) facility equipment/systems/areas not having been virtually (or physically) inspected for

[31] "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
[32] Matrix Technologies

extended time periods; (2) risk based inspection (RBI) results; (3) critical equipment sparing levels (e.g. shortages of spares that might impair rapid recovery from any maintenance issues that might develop); (4) critical equipment intervention competencies (i.e. potential extended durations to mobilise trained maintenance personnel and/or specialist tools); or (5) regulatory issues or constraints (i.e. unavailable documentation or surveys/inspections) that might impair the ability to continue production.

As noted in the previous section on visualisation, operators need assistance to help visualise data associated with complex facilities and operations in order to gather insights, make decisions, and maximise value. In the case of risk management, operators need to be able to be proactive and stay ahead of any material issues developing, and fortunately we have some good tools including 6D BIM type visualisation of IoT data and data analytics available to help. Remote, unmanned facilities within any industry should use these tools to manage risk efficiently without unplanned interruption of activities which would lose value.

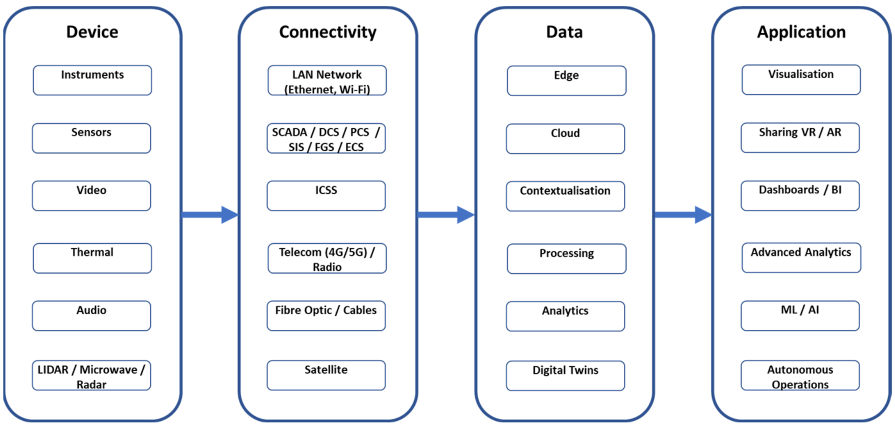
9. Reducing Operations and Maintenance Costs

In a disrupted energy markets price environment, it is crucial to find ways to reduce costs for existing assets. Unnecessary operations and maintenance activities need to be curtailed, deferred, or cancelled. In most asset teams, this is a routine performance target, but with public health issues combined with the low energy prices, it has become even more urgent. There are existing Digital Transformation tools and modified work practices economically available to help reduce these costs. A key aspect of these cost savings is to reduce the numbers of personnel required to be physically located in the field. Remote working also reduces the amount of time spent going back and forth from centralised offices to remote field locations for other workers.

Most existing energy industry facilities have safety and control systems in place that can be used to help implement increased remote monitoring and diagnostics. Existing data is not being used very well – but it is already streaming through ICS systems so it is probably available to be captured and used remotely.

We need more than the basic data that feeds standard dashboards. Dashboard data is a useful tool for all operators, whether located onsite or remotely, but it does not usually have the fidelity needed for advanced data analytics. The data fidelity from periodic instrument readings is however useful to compare with the virtual instrument readings from a dynamic simulation model being used as a Digital Twin. These comparisons would allow remote operators to have confidence that the physical facility was operating as expected if it correlated to the theoretical performance of the Digital Twin model. Occasionally we have instruments that drift or fail and a Digital Twin model with virtual instrument readings would demonstrate that no immediate response was required and the normal instrument maintenance could be deferred to the next regular maintenance campaign as long as the majority of other physical instruments were still being validated by the Digital Twin results.

A key way of reducing operational costs by reducing (or eliminating normal manning) is to ensure the facility data flows shown below are able to be passed through to remote teams who can use this data to monitor the integrity of the field facilities and remotely make any changes needed to operational settings:



For better evaluation of IoT data, we typically need to capture higher fidelity data which may require additional bandwidth communications. Existing facilities may have communications more suited for routine voice and email communications from field teams back to home office teams, but there is often an existing system for dashboard type data (e.g. *OSIsoft PI*). Upgrading communication systems is getting easier and cheaper as technology advances. Bandwidths have increased, latency decreased, and data flows are getting more economic due to competition. Previous sections described in more detail what kind of communication systems are available, often at the same cost or even reduced cost with historical communication systems so it is worth investigating these opportunities to obtain the data capability needed for unmanned (or reduced manning) remote operations.

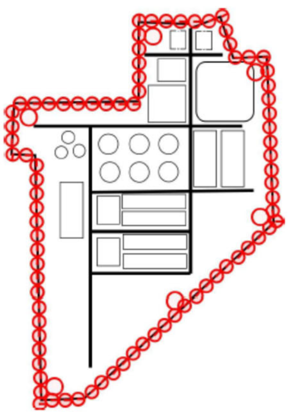
To reduce the numbers of field personnel, we need more visual and audio data. Physical inspections can be potentially reduced with the use of remote observations from cameras. Existing security system cameras could be used, but probably are more focused on perimeter intrusion detection. These systems can be repurposed and extended (using the same video system networks) to have more cameras directed inside the perimeters focused on equipment. Pan–tilt–zoom (PTZ) cameras can be dual (thermal/colour) and, if only linked to manual viewing systems, they can be improved with advanced video analytics and video motion detection software easily added to these systems to help remote monitoring capability without constant manual monitoring. In addition, unstructured manual viewing is able to be transformed into structured data flows through the use of analytics and recordings. Further significant improvement can be with the addition of Radar Video Surveillance (RVS) detection systems linked to the cameras:

Conventional CCTV Camera/Pole

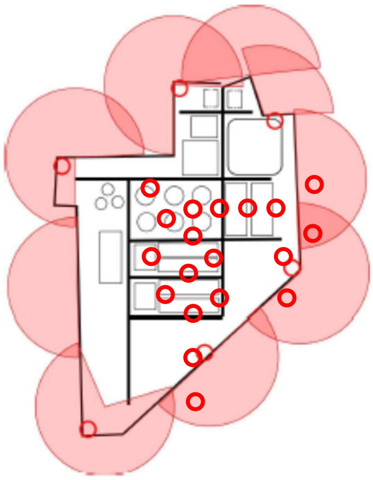
Dual (thermal/colour) Camera

Linked Ground Radar Device

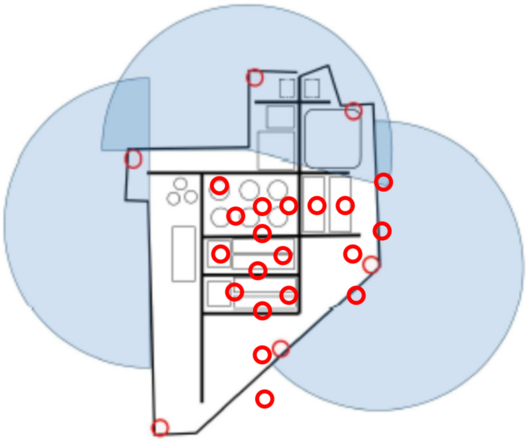
RVS systems would allow a very high percentage of fixed CCTV cameras to be relocated from the perimeter to cover critical equipment inside the facility[33]:



Standard CCTV Poles (@100m spacing)



RVS Poles (700m range camera @900m spacing)



RVS Poles (1400m range camera @900m spacing)

[33] https://www.honeywellprocess.com/en-US/online_campaigns/Radar-wp/Pages/RadarVideoSurveillance.pdf

In the example sketches above, 79# poles with 36# PTZ and 164# Fixed Thermal Cameras (left image) were reduced to significantly less perimeter poles with dual (thermal/colour) cameras and short range radar systems. This means many of the original (existing) cameras could be relocated inside the facility to support remote monitoring whilst perimeter intrusion detection capability was maintained. Thermal cameras focussed on equipment, machinery, and piping should actually be able to detect changes or anomalies that field personnel might miss, especially if these changes were located underneath insulation (e.g. corrosion under insulation).

Cameras focussed on equipment should also have auxiliary sound detection capabilities linked to advanced audio analytics[34]. Audio analytics would be able to listen for sounds correlated to operational conditions and prepare a database of what is "normal" and what is anomalous (requiring remote operator attention). This is actually similar to what experienced field operators do on their rounds – listening for anything out of the ordinary. Now we have a way with distributed audio sensors to listen in the same way (across a wider frequency range) but at the same time create structured data of these sounds. When some equipment begins to degrade, the sounds they make change with time and it can be a leading indicator of maintenance requirements or the need to adjust operating settings.

This kind of visual and audio monitoring reconfiguration would provide remote operators increased surveillance capability to complement the structured IoT data being received through the ICSS and/or *OSIsoft PI* dashboards.

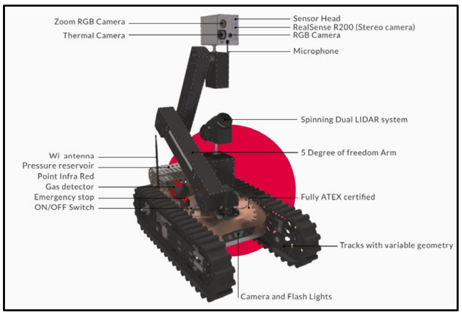
Another potential solution to increase visual surveillance is "Drone in a Box" – this solution is autonomous drones remotely operated but stationed in the field in storage containers where the drones are docked and recharged. Multiple contractors currently provide this kind of tool[35]. Reductions in expensive field manning should easily cover the cost of these systems.

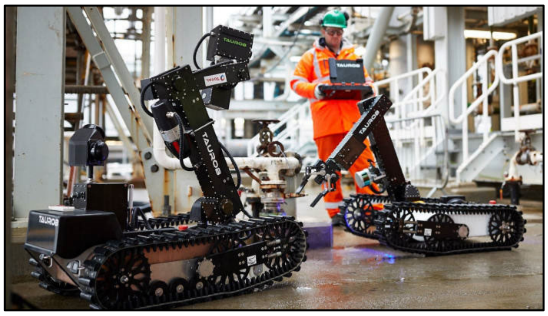

One such provider is Percepto who states that "Using thermal imaging and on-board Artificial Intelligence (AI), advanced autonomous drones can detect temperature variations that could lead to overheating or fires, or anomalies in sensitive locations that could be indicative of gas leaks and oil spills."[36]

A key part of autonomous surveillance is the ability to perform ongoing video and thermal imaging analytics to detect anomalies that may develop over a period of time. Daily physical inspections by experienced personnel might catch these kinds of issues, but machine learning algorithms based on images from fixed or PTZ cameras or drone cameras "enable higher volumes of data to be collected consistently and at higher frequency, (so that) modeling and forecasting of maintenance & production can be improved"[37] with historical records available for review at any time.

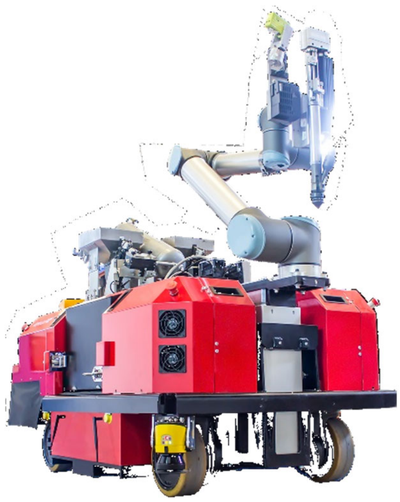
[34] http://www.soundintel.com
[35] http://cdn.flytbase.com/wp-content/uploads/2019/07/Security-Whitepaper.pdf
[36] https://percepto.co/
[37] https://percepto.co/are-autonomous-drone-operations-more-expensive/

Another technical tool which could be economically deployed in an existing asset is certain kinds of robots:





Shell has a remotely-operated mobile robot that inspects and monitors industrial facilities[38] called *Sensabot* developed together with the National Robotics Engineering Center at Carnegie Mellon University[39]. Total has a robot called *Argonaut* developed together with Taurob Gmbh (Austria) and researchers from Darmstadt University of Technology (Germany)[40]. There is a major push in multiple industries for these kinds of robots for hazardous area inspections and they are also well suited to unmanned inspection of remote facilities. After each inspection, the robot would return to its docking station to recharge and transfer any high bandwidth data not already transmitted by Wi-Fi or cellular. With these kinds of inspection robots, structured inspection data can be captured and then evaluated with video and thermal analytics.



Some of these kinds of robots are being developed with intervention capabilities (manipulator arms) which will increasingly be useful for routine, simple maintenance tasks (e.g. partial cycling of manual valves to help prevent lock-up). Remote operators can use cameras onboard these kinds of robots with their manipulator arms to perform facility activities in lieu of needing field personnel. The two examples shown above are from Robotnik-Spain[41] [42].

These robots can also perform certain autonomous activities and move around sites avoiding obstacles without direct remote operator control all the time. Robots do not have to be fed, housed, entertained, rotated back home, transported, or concerned with duty of care. Remote operators can live at home, safe from field and travel risks.

[38] https://www.shell.com/inside-energy/a-bionic-inspector-rolls-in.html
[39] https://www.nrec.ri.cmu.edu/nrec/solutions/energy/sensabot-inspection-robot.html
[40] https://www.eenewsanalog.com/news/total-design-autonomous-robots-inspections/page/0/1
[41] https://www.robotnik.eu/manipulators/xl-gen-2/
[42] https://www.robotnik.eu/manipulators/rb-vulcano/

If the nature of the facility asset or the type of maintenance work requires some form of minimal constant manning, then we need to address how to make these workers be as productive as possible in order to reduce the overall numbers required to help reduce costs. Augmenting these workers with better knowledge, tools, work flows, and work practices is needed to improve efficiency. Remote facilities have historically had maintenance efficiencies as low as 15-20% (with the average around 30-40%) for a variety of reasons which resulted in higher field staffing levels to get the work completed. Some of the maintenance work pre-requisites to improve efficiencies:

- Workers need to have the necessary competencies, the right materials and tools, and familiarity with the procedures and details required;
- There needs to be pre-planned job safety analysis (JSA) completed prior to the work;
- Isolations of energy (i.e. power, pressure, extreme temperatures) need to be in place safely;
- Any simultaneous operations or maintenance needs to have been considered in planning and executing the work;
- Work has to have been planned to be accomplished in manageable steps with the ability to exit the work task safely if unexpected physical conditions are encountered (e.g. excessive contamination inside a vessel) that may require additional preparations or tools or different procedures.

As discussed in prior sections, many of these pre-requisites should be able to be facilitated with Digital Transformation tools including Digital Twins, accessible contextual data inside Cloud Data Platforms, Enterprise Asset Management systems (especially Asset Performance Management and Maintenance Management subsystems), training (e.g. with VR), and field support (e.g. with AR). Multi-skilled field workers supported by remote ARconnected SME’s is a good way of reducing field numbers. When a maintenance task is scheduled to be performed, the most cost-effective outcome is the maintenance worker going out and performing the right work, correctly performed the first time, in the amount of time originally estimated for the task. Unfortunately this doesn’t happen very often unless better preparations are made with improved technical support for these workers, so value is lost with increased costs and delays. This is an opportunity for Digital Transformation to help capture more value.

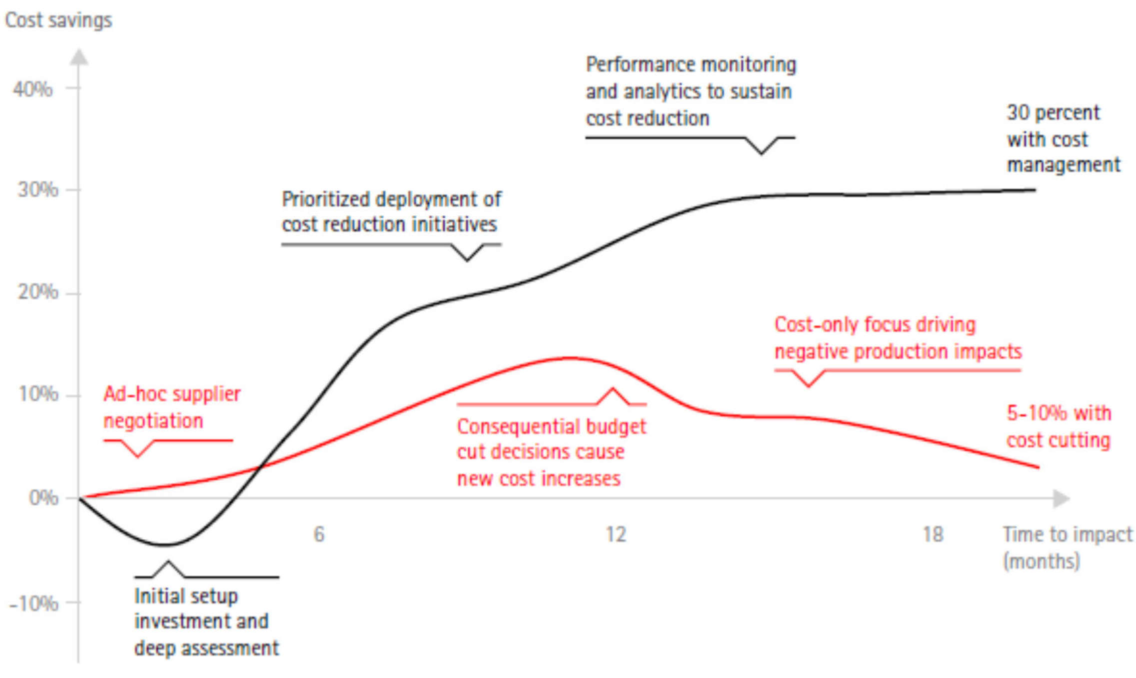
Another source of inefficiency in field facilities it how inspections and records are performed. Paper based processes should be eliminated with online forms (“Digital Process Automation” or “Workflow Management System”) to help minimise time in the field making a reduced number of field workers more efficient (“50% increase in efficiencies on any paper based process” – ref. *FlowForma*). Mobile apps with automatic report generation can be linked to geolocation and temporal data so that structured data is quickly and correctly prepared for use by remote management and technical support users. Field workers could perform field inspections with tablets, smart devices, or AR headsets that guide them to the necessary workfaces and then automatically record visual and audio records of what was inspected in additional to online documentation being completed. Any queries could be resolved on the spot with remote technical experts conferenced into the inspection virtually. Completed forms and associated support documentation would be directed to various end users, the Cloud Data Platform, and applicable actionees with email notifications:

Field maintenance is always going to be needed, especially preventative maintenance, but the goal is to perform maintenance when actually needed and performed "right the first time". Maintenance schedules need to be reviewed to see where routine scheduled maintenance periods can be extended based on data analytic results. Equipment needs to be monitored and operated inside Integrity Operating Windows to help minimise potential sources of degradation. Maintenance should be reviewed as follows:

- Short term – essential fabric maintenance (e.g. protective coatings or insulation), lengthen routine maintenance intervals based on experience;
- Medium term – utilise predictive maintenance data analytics to better estimate required maintenance intervals; gather performance databases and utilise ML/AI to identify potential "failure signatures" to proactively get ready to replace degraded systems;
- Long term – agree shared risk and rewards with key equipment suppliers for improved performance and reduced maintenance – utilise collaborative healthcare contracts with remote monitoring and diagnostics as well as sparing inventories and some maintenance tasks by suppliers;

Asset teams should be small, multidiscipline agile teams utilising best available remote monitoring and diagnostics as described here. Some members of these teams could actually work from home to save costs for companies (reduced office costs) and employees (reduced time and cost to commute) using visualisation and communication tools. Some technical support could be located across multiple assets "in the field" by using mobile "offices" (their vehicles) with better mobile communications allowing them to visit remote facilities on a rotating basis and eliminating the need to make trips back to home offices – wider team engagements could use *MS Teams* or software like *Zoom*.

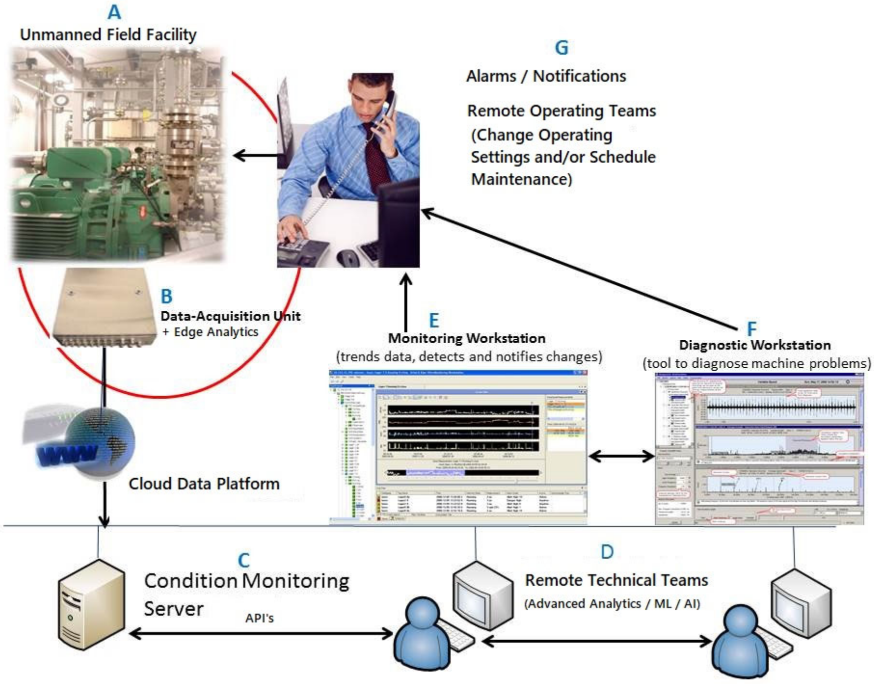
An important strategic recommendation from *Accenture*[43] is to focus on operations and maintenance cost management, not just cost cutting. This involves a change in culture to place greater emphasis on planning, changing how teams and decisions might have historically worked, and focussing on continuous improvement - delivering quality the first time, every time.



Source: Accenture Strategy, Energy analysis

43 https://www.accenture.com/t20160527t044628__w__/us-en/_acnmedia/pdf-11/accenture-8-strategy-energy-perspectives-five-essentials-for-improving-operating.pdf

A corollary recommendation[44] is “Do not let tradition get in the way of progress. It’s important to revisit old processes, vendors, and employee standards to ensure your company is operating as effectively and efficiently as possible.” Digital transformation can provide cost effective tools but companies have to change how they work also to be successful with the current industry challenges.



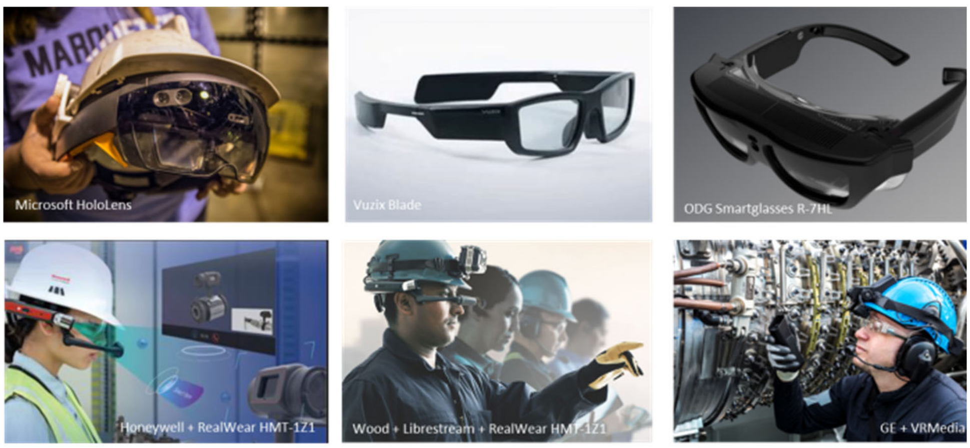
Example of Remote Monitoring and Diagnostics

[44] https://micotan.com/operational-costs/

10. How Augmented Reality Can Help Operations and Maintenance

Augmented Reality (AR) is a powerful tool to help field personnel in remote facilities to better operate and maintain their assets. Increased use of robotics likely will be a key part of the future operations and maintenance of these facilities, but in the meantime, we have tools which can "augment" the capabilities of the current field personnel. Reducing the numbers of field personnel to help reduce costs doesn't have to mean being less effective in asset performance management and integrity if we use digital transformation tools appropriately.

From a previous section we understood that there are various technologies to access this AR including smart handheld devices and some types of wearable headsets. Here were some photographs of these technologies. The purpose of this section is not to go into the hardware aspects of these items, but rather to discuss how they can help field teams.



Unless we are discussing a "not normally manned" (or unmanned) facility, field teams are located in these remote facilities to perform specific operational and maintenance tasks. There may be critical operations that require the physical presence of these teams. Complicated maintenance activities similarly may require the physical presence of these teams. We need to optimise the number of field workers to help reduce OPEX costs.

Previously large field teams may have had workers categorized with a number of specific job titles and disciplines separated into functions and areas of the facility. This practice led to larger teams than might be currently considered optimal. One example of a deep well drilling rig crew had an operational crew, a mechanical maintenance crew, and an electrical maintenance crew. Each type of crew had engineers and technicians. Work assignments and practices were restricted for each type of crew. This situation was uneconomic and there was a low utilisation factor of workers. Best practice would be to consider multi-discipline personnel staffing this facility and breakdown the work constraints. Sourcing a multi-discipline crew is a good first step, but AR and digital transformation offers a way to enhance the capabilities of such an organisation by multi-skilling them.

Reduced numbers of multidiscipline personnel would be very capable of some tasks but would be less familiar with other tasks. AR is a way to provide remote technical expertise directly to these workers when they are performing such a task. Initially these workers could have received multi-skill training by viewing Virtual Reality (VR) recordings of the applicable tasks, the tools needed, and the sequences of work – prior to mobilisation and going into the field.

Then during the actual field maintenance work, particularly for a complicated diagnostic task, the field worker could be speaking (conferencing) with a remote technical expert who would be able to simultaneously view the work through the inbuilt AR cameras. These remote technical experts could support multiple field teams whilst either (1) located in corporate function teams or (2) located in equipment supplier teams under healthcare contracts (e.g. for gas turbine power generation equipment).

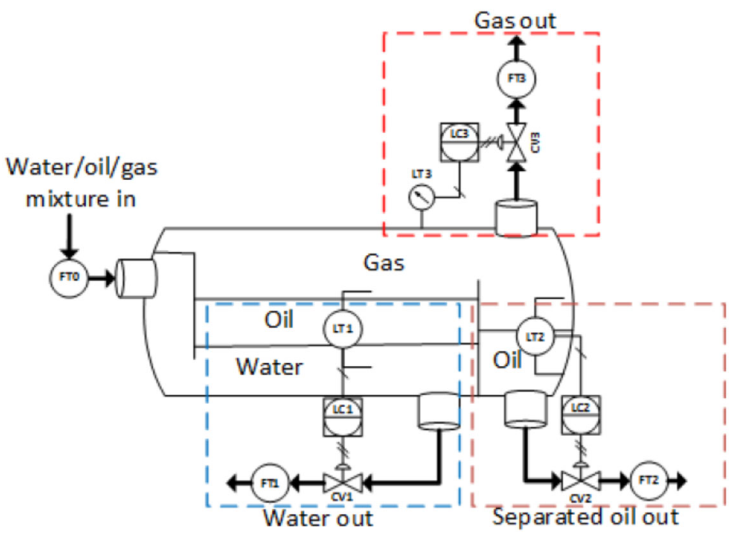
Remote technical experts can supply real-time support to the field workers by being able to access any historical contextual data associated with the equipment such as engineering calculations, vendor test results, details of spare parts, and confirmation that correct maintenance procedures were being followed (e.g. technical assurance for the field worker). For especially critical field interventions whilst live production was ongoing in the facility, these remote technical experts could also help ensure that there was sufficient isolation in place. Unfortunately there are numerous industry safety incidents where the wrong piece of equipment was isolated whilst field workers actually worked on another piece of equipment.

Field operations and maintenance workers using AR can also simultaneously document the work being performed, whether it is routine or exceptional. The AR equipment can track and document spatiotemporal data to provide confirmation that the correct work was being done in the correct locations at the correct times. The inbuilt AR camera could capture video and photographic records of facility and equipment conditions for ongoing risk based inspection activities. This data and these records could be online, paper-less, automatically processed ("Digital Process Automation"). All these contextual records would then be added to the Enterprise Asset Management (EAM) / Asset Performance Management (APM) systems inside the Cloud Data Platform.

The following illustrations show the kind of AR visualisations being used by some field teams.

First example of a physical facility view (main view) and a 3D CAD model of the same facility view (inset view). Such a composite view would be typical for a field worker using AR upon first approaching the piece of equipment (or pressure vessel in this example). Within the 3D CAD view window are a number of selectable objects with linked contextual data which could be accessed by the worker.

A typical 3-phase process separator would consist of the vessel, fluid (oil and water) measuring systems (turbine meters), an electronic gas flow measurement system, and various sampling points. Pneumatic regulators would maintain a constant process and constant liquid level inside the vessel using control valves on the oil, water, and gas outlet piping. Additional components could include an internal electrostatic coalescer, effluent diverter tube, mist extractor, vortex breaker, and weir plate – depending on the multiphase fluid properties, rates, and residence time. One of the functions of the control systems and components is to reduce the risk of liquids in the gas outlet ("carry over") or gas in the liquid outlet ("carry under"). Some amount of solids might also be possible in the production fluids. Chemicals might be used to help manage flow assurance issues like foaming, solids deposition (i.e. scaling or asphaltenes), corrosion inhibition, and emulsion breaking.



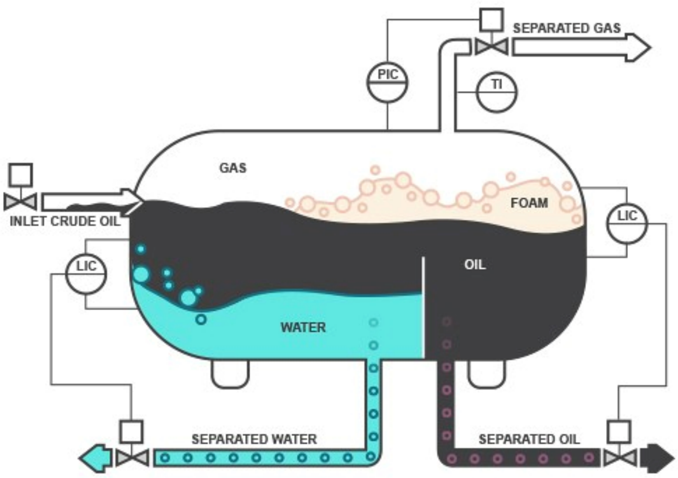
Any these components and associated instruments may require diagnostics or maintenance and the ability of AR to link the field worker with supporting information would make this kind of work much easier and more reliable.

Obtaining information such as (1) what does "normal" physical condition look like, (2) what kinds of field adjustments are possible, (3) where access and intervention points are located, (4) types of tools necessary to perform maintenance, etc.

A multi-discipline, multi-skilled field worker could competently perform adjustments and replace certain instruments where required with AR support by linking to the underlying contextual data in the 3D CAD Digital Twin model.

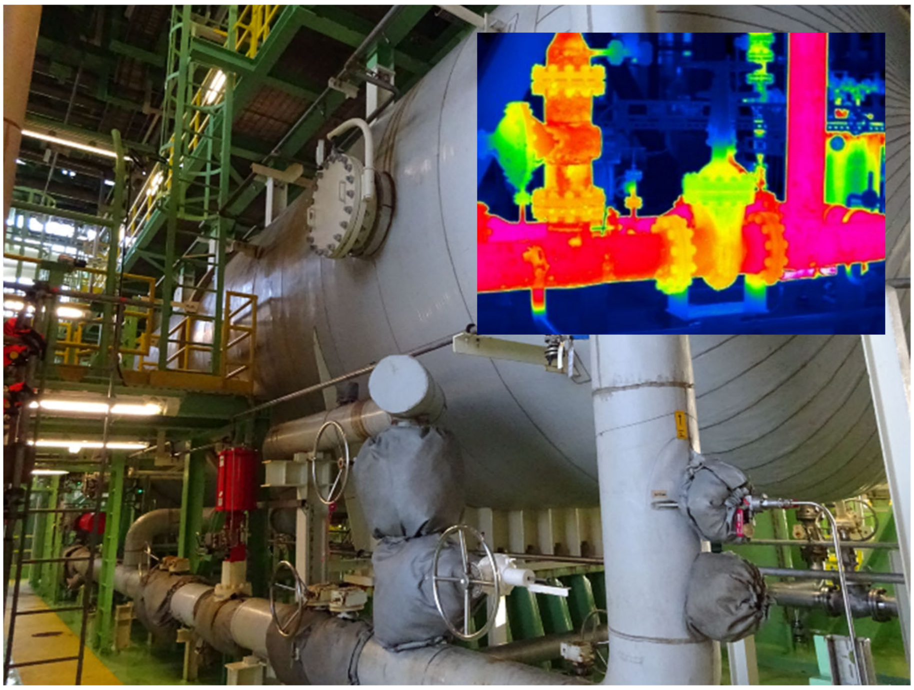
Next example of the previous physical facility view (main view) and a virtual (graphical) internal representation of the same pressure vessel (inset view). Such a composite view would be useful for a field worker using AR with live process data showing internal fluid levels and compositions (i.e. solids, water, emulsions, oil, and gas). This kind of data visualization would be available from analytics processed level instrument data.

Visualisation of data has been seen to enable workers to better appreciate ongoing physical processes, in this case normally hidden inside this pressure vessel. Diagnosis of potential level instrument errors could facilitate knowing what to replace or maintain. Instruments can drift off calibration but could also have connectivity issues to be remedied. Control valves could have (1) minor preventative maintenance (i.e. adjusting stroking check, stroking mismatch, changing damaged accessory gauges or connectors, changing damaged/degraded metallic tubing, regulator backflushing, or cleaning and greasing) or (2) major preventative maintenance involving replacing the field valve and taking the original valve back into the shop to overhaul or change major parts.



Flow assurance issues like foaming might also be better diagnosed with AR. Foaming can be a difficult problem to predict and then diagnose and it can severely affect performance of the separator by confusing level controllers. Well test crude samples may not adequately predicted the foaming tendency of some oil gravities. Temperature (heating) can often help but a light oil with low GOR might also have increased foaming tendencies instead. Foam depressant chemicals can help but they can be expensive and the dosing rate needs to be adjusted to just what is needed. There may be other adjustments possible to separator internals to reduce foaming. So diagnostics and remedial actions can be complicated and having a field operator able to make iterative adjustments based on AR retrieved data might speed up rectification of this issue.

Next example of the previous physical facility view (main view) and a thermal imaging camera view of process piping within this facility (inset view). Such a composite view would be typical for a field worker using AR with a thermal imaging camera. Distributed temperature gauges may or may not catch localised hot or cold areas which might help diagnose process anomalies (e.g. flow assurance issues) or other problems.



Asset integrity sometimes requires identifying things that are hotter than they are supposed to be or else colder than they are supposed to be. We can often identify this from time consuming manual inspections, but if real-time AR thermal imaging camera data is automatically processed through video analytics, then the results can be compared with theoretical Digital Twin surface temperatures to more reliably identify potential issues.

Corrosion under insulation (COI) is a major challenge to process industries. We have insulation to protect process fluids from cooling (where we want them to stay warm) or to protect workers from accidental contact with elevated steel temperatures. Meanwhile moisture can get underneath this insulation and with coating breakdown with time (or inadequately applied initial protective coating) there can be corrosion cells. It has been estimated that up to 60% of pipe leaks are due to COI. Field teams using the AR thermal imaging camera can walk around a facility looking for thermographic evidence of potential COI (usually by differential surface temperatures caused by the moisture), automatically record the locations for increased inspection, and get ready for potential remedial work.

From these simplified examples, we can see that Augmented Reality hardware and software can "augment" the capabilities of field personnel. Better, real-time data visualization, especially data processed by advanced analytics or extracted from Digital Twins, is one of the most important outcomes from the use of AR helping field teams. We want to improve technical process safety through better appreciation of field facility conditions and integrity. Improved field safety and better asset integrity will improve reliability of production and hence more constant recovery of value. We want to perform maintenance when really needed, completed efficiently and right the first time. Reducing the numbers of field personnel to help reduce OPEX costs doesn't have to mean being less effective in asset performance management and integrity if we use digital transformation tools like AR appropriately.

Augmented Field Worker

11. How Virtual Reality Can Help Operations and Maintenance

Virtual Reality (VR) is another useful tool to help distantly located operating team personnel remotely operate and maintain isolated and minimally manned (or unmanned) facility assets. In several recent sections, I have described “virtual rounds” by these personnel. What is a “virtual round” and how are remote facilities visualized and reviewed?

It all begins with a contextualised 3D CAD model (or a contextualized 3D scanned point cloud model). As described previously the underlying computer models are routinely developed during greenfield (newbuild projects) or brownfield (existing facility modifications) design engineering. These models are normally prepared for procurement and construction purposes but they are as valuable to be used as life cycle models with contextual data attached to individual tagged items. Data needs to be accessible throughout a facility’s life cycle and unfortunately this does not always happen. Searching for data causes significant cost increases and delays in construction, operations, and maintenance (and errors when not found). Some structured data from analytical models is usually available but much of the potential data could be unstructured data and is often “lost”. Contextual 3D database models help preserve this data and VR can be a user friendly way to get into this data and find what is needed quickly.

Once a 3D model is prepared, contextual data should be continuously added during engineering, procurement, construction, pre-commissioning and commissioning, and then during start-up and operations. Every piece of equipment has design data, manufacturing data, and testing data which is available to be placed into a contextual database. Drawings of each component and details of how constructed and training videos of how to perform disassembly and maintenance are invaluable for eventual operating and maintenance teams. Visual details of what “normal” looks like (when first installed and at the start of operations) are useful to help identify future potential degradation and maintenance priorities. These databases need to be kept live and the cost to do so will be minimal compared to the costs associated with lost data and any resultant mistakes in operations or maintenance.

Once we have the virtual model of the physical facility it can be “entered” by the user. VR can be visualised with various systems ranging from wall mounted touch screen monitors to desktop computers to handheld tablets. For purposes of the "virtual round" however, we could consider headset VR systems like the ones shown below:

Many VR headsets are able to view virtual reality views inside the 3D model as well as live or recorded video from visual or thermal imaging cameras. VR can also be used to visualize dashboards and ICSS HMI data. VR provides an immersive experience for users with multiple forms of data flow possible. VR has been well received for training, but with modern IoT devices, high bandwidth communications, and Digital Twins, it is possible to perform "virtual rounds".

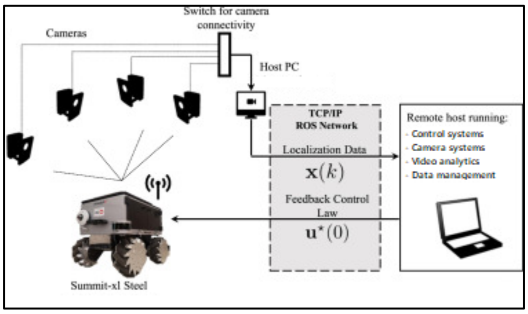
A "virtual round" would start with the remote operator donning the VR headset and initiating the 3D model. Movement through the model is possible with various auxiliary tools including handheld control devices. The user's view is shown at right below with a human avatar representing the user's position inside the model. Movement through the model is possibly by "flying" or "walking" in any direction. Inspection routes could also be programmed for repeatability. Inspections would be automatically documented for subsequent use by any interested parties.

As the user moves through the model, it is possible to "look" at elements such as equipment or piping or electrical systems, and to "select" them for access to the underlying contextual data (i.e. live operational IoT data or advanced analytics processed data). As an inspection proceeds, as described in a previous section, some of the virtual equipment representations could be graphically colour coded based on whatever underlying data/parameters had been identified to be visualised. For example, tagged equipment running at the edge of their integrity operating windows (or worse outside these windows) could be highlighted for the VR user to notice, then select the item and examine live process data to determine if any intervention is required or possible. As described in a previous section, there will normally be a number of video and thermal imaging cameras distributed throughout a facility, so at any time during this "virtual round", the user could switch over to nearest PTZ cameras to see if there is anything notable to observe (potentially linked to the data analytics notifications).

Infrastructure facility surveys using LIDAR have been conducted and then later inspected in a VR environment[45]. These facilities have typically had four categories of inspection: Safety Inspection (routine surveillance), General Inspection, Principal Inspection, and Special Inspection. Safety Inspections were performed at "frequencies which ensure timely identification of safety related defects which might lead to accidents or high maintenance costs in the future". General visual inspections were performed about two years after construction completion, then Principal Inspections were performed at six year intervals. If a flaw was discovered, a Special Inspection would be performed to ensure integrity is maintained or any maintenance identified. In the above reference, visual inspection parameters included: (1) geometric measurements; (2) cracks; (3) differential movements; (4) open joints; (5) degree of wetness; (6) mortar lose; (7) leaching; (8) chemical attack; (9) eroded surfaces; and (10) presence of vegetation. An analogous set of inspection parameters are possible for multiple types of remote production and process facilities. Image datasets could require significant memory size and processing capabilities in the data systems, but machine learning should be able to filter out unremarkable data and concentrate on changes from prior surveys. Edge analytics could look for differences from a baseline digital twin model and report anomalies.

Infrastructure facilities are likely less complex than production and process facilities, but the same general strategy could be identified with different time intervals for more complex facilities. In a manned production or process facility, there are physical rounds typically every shift and these could be characterised as safety inspections (possibly just using video and thermal imaging cameras in VR visualisation mode). General inspections could be more rigorous (maybe using LIDAR recordings then viewed in VR) and could take place yearly depending on IoT data from the energised (pressure, temperature, power etc.) production or process systems. Special inspections would follow any routine inspection that found any anomalies. In a remote, unmanned facility scenario, the safety and general inspections might by made by remote operators with VR linked systems (i.e. Digital Twin models with contextual operations data, video and infrared cameras, and audio). Any questionable anomalies could instigate a physical inspection by field maintenance teams.

Another example of a potentially useful tool concept is a multi-camera VR system (*Ref. Jaunt One VR*) mounted on a mobile robotic vehicle (*Ref. Robotnik Summit-XL*) which could autonomously (or directed manually) move around a facility allowing routine structured data recordings of the facility. Video analytics could automatically scan for potential anomalies for expedited review by remote operators. Otherwise the remote operator could have a live VR inspection with all data compared to historic data stored in the contextual database for evaluation of potential anomalies.



[45] Muhammad Omer, Lee Margetts, Mojgan Hadi Mosleh, Sam Hewitt & Muhammad Parwaiz (2019) Use of gaming technology to bring bridge inspection to the office, Structure and Infrastructure Engineering, 15:10, 1292-1307, DOI: 10.1080/15732479.2019.1615962

An interesting feature inside some VR visualisations using game engines, is multi-participant networked ability[46]. Multiple users could represent themselves as avatars and interact with each other inside the virtual model regardless of their physical locations. An example is a virtual inspection to diagnose an issue with a piece of rotating equipment – imagine an asset team member in London interacting with a SME from the equipment supplier in San Diego with the physical equipment located in a remote African field location. These users can point or wave to components of the equipment or highlight data for each other and conference for diagnostic evaluations and potential remote interventions[47]. This ability could save significant cost and time to resolve any complicated field issues.

Virtual Reality (VR) is a useful tool to help distantly located operating team personnel remotely operate and maintain isolated and minimally manned (or unmanned) facility assets. The ability to rapidly access and visualize contextual data for facility equipment and systems is an essential part of better operations and more reliable maintenance. Our asset teams and operational personnel can be centrally located but able to visualize and inspect multiple remote unmanned facilities wherever they are located. Maintenance personnel will still have to make periodic field visits but they should be better prepared prior to making these trips. There are several good suppliers of these VR tools and they need to be carefully linked into contextual databases maintained throughout the life cycle of an asset.

[46] "Virtual Architecture: Modelling and Creation of Real-Time 3D Interactive Worlds", Mohd Fairuz Shiratuddin, Kevin Kitchens, Desmond Fletcher, Lulu.com, 2008

[47] https://www.dogheadsimulations.com/rumii

12. How to Start Improving Remote Facilities for Better Operations and Maintenance

Lots of discussion and suggestions for potential digital transformation technologies, tools, workflows, and organisational change – how should you start to improve your remote energy industry facilities for better operations and maintenance?

Most energy related industries have remote facilities including (1) oil and gas; (2) solar farms; (3) wind farms; and (4) distributed power generation. All of these energy industries have similar challenges to safely and efficiently operate and maintain these facilities.

Common energy industry elements include: (1) safety and performance design criteria; (2) engineering calculations (analyses and design); (3) vendor data; (4) operating plant with energised equipment (i.e. electrical power, pressure, and/or temperature); (5) safety and control systems; (6) physical plant with fabric maintenance considerations; (7) technology to monitor processes and events with visualisation through human machine interfaces (HMI) that may be local or networked; (8) security considerations to protect the asset and/or from potential intruders; (9) inputs (i.e. natural resources, raw materials, human resources, capital) and outputs (i.e. products or services); (10) environmental considerations (i.e. weather, discharges, impacts); and (11) CAPEX and OPEX considerations in life cycle value evaluations.

All of these energy industry elements are able to be better managed with digital transformation technologies, tools, work flow changes, and organizational cultural changes. We call the aspirational outcome **Integrated Intelligent Operations and Production**:

1) Safety design criteria involve the facility being safe for the environment, any people working inside the facility, communities outside the facility able to be affected, and the performance integrity of the asset itself. Performance design criteria are that the facility has performance output requirements and the business purpose is to deliver a valuable outcome for the owners that will reliability deliver the business case outcomes;
2) Engineering calculations for each facility involve analyses and design work to allow the facility components to be procured and constructed and made ready for operations – this engineering will be a valuable source of data throughout the life cycle of the asset and it needs to be kept accessible;
3) Vendor data comes from the supplier of the equipment and systems included inside each facility and it can range from engineering to subcomponent data to assembly and testing to final completion details – this data will be needed for eventual operations and maintenance of the facility including diagnostics and spare parts and it should be kept accessible including inside the Enterprise Asset

Management/Asset Performance Management systems residing inside an accessible, multi-user Cloud Data Platform;

4) Operating plant are energised with some combination of electrical power, pressure, and/or temperature and this energy needs to be reliably controlled to produce the planned outcomes from the facility;
5) Safety and control systems (i.e. PLC, DCS, SCADA,SIS, ICSS) for these facilities help ensure safe predictable operations from both local as well as remote operations centres handling multiple remote facilities;
6) The physical plant of these facilities helps structurally and mechanically support and protect the equipment and systems. Fabric condition needs to be monitored (in structured data) and maintenance needs to be performed to ensure safety and control are not jeopardised by physical plant issues;
7) Supervisory Control and Data Acquisition (SCADA) type systems display the industry process under control and provide access to control functions. Visualisation is through Human-Machine Interfaces (HMI) which are a field or remote user interface or dashboard that connects users to a machine, system, or device inside these facilities. HMI's visually display data including monitoring inputs and outputs and they are accessible through many types of local and remote electronic devices (i.e. handhelds, wearables, desktop, kiosks, wall panels);
8) Security considerations include physical security as well as cybersecurity. Remote assets, either unmanned or minimally manned, could have unwanted visitors who may accidentally or maliciously cause damage resulting in safety and environmental risks as well as potential financial loss. Cybersecurity is a concern with threats and interference in safe operations including deliberate damage by changing safe equipment settings or blocking the transmission of electronic data;
9) Inputs (i.e. natural resources, raw materials, human resources, capital) and outputs (i.e. products or services) have to be prepared, implemented, monitored, controlled, and able to be modified in response to any changing field or market conditions;
10) Environmental considerations (i.e. weather, discharges, impacts) are physical, regulatory, and/or market constrained. The operations of a remote facility may need to be remotely adjusted to accommodate both routine as well as extraordinary conditions (i.e. wind direction, wind speeds, cloud cover, precipitation, and/or metocean). Regulatory constraints could be restrictions on discharges or noise. Market constraints could be energy market disruptions (i.e. oil price or electricity price);
11) CAPEX and OPEX considerations in life cycle value evaluations involves selecting the best equipment and systems in the start of a development to deliver the desired reliability, operability, and maintainability over the course of an entire life cycle – not necessarily selecting something that is just low initial cost since it might have higher maintenance costs or worse might have undependable uptime or performance. Life cycle cost evaluations have to explicitly think about operations and maintenance and how they are going to deliver the best outcomes. Lost value from shutdowns can quickly exceed any initial cost savings.

The reasons for improving the operations and maintenance of these remote energy industry facilities are readily apparent:

- Current disruptions to energy market pricing means that these costs are a priority target to be minimised; one of the most significant variable costs is manpower – reducing headcounts can save significant OPEX (each remote field worker could cost up to $200,000-500,000/year (or more) for salary, burden, overhead, transport, housing, etc.) – but we need to ensure that asset integrity is not jeopardized by reducing manning;

- Safety risks of personnel travelling back and forth and actual physical presence in the field are among the highest safety risks faced by an asset team, so reducing or eliminating travel can improve the overall safety profile;
- Operational settings need periodic change so better data and analytics to get insights to make decisions necessary to modify these settings is required – and ideally we want to make these operational changes remotely without needing field visits (other than for required maintenance);
- Better IoT data will help identify predictive maintenance needs sooner and mitigate "fix it after it fails" scenarios – sometimes the existing safety and control instruments do not provide the fullest picture of potential equipment degradation and other developing maintenance issues;
- Training of operational teams is better done with Digital Twins, Operational Training Simulators (OTS), and VR as discussed in previous sections – in a previous study of North Sea compressor trips, it was found that ~40% of the trips were due to inadequate operator responses to normal operational events – and better training could help resolve this thereby delivering more uptime and value;
- Support for field maintenance teams during their work (doing the right maintenance at the right time, personnel competencies, right tools, right spare parts, correctly isolated, correctly disassembled replaced and reassembled) is a priority based on industry statistics that show significant leakage of value by incorrect or inefficient maintenance.

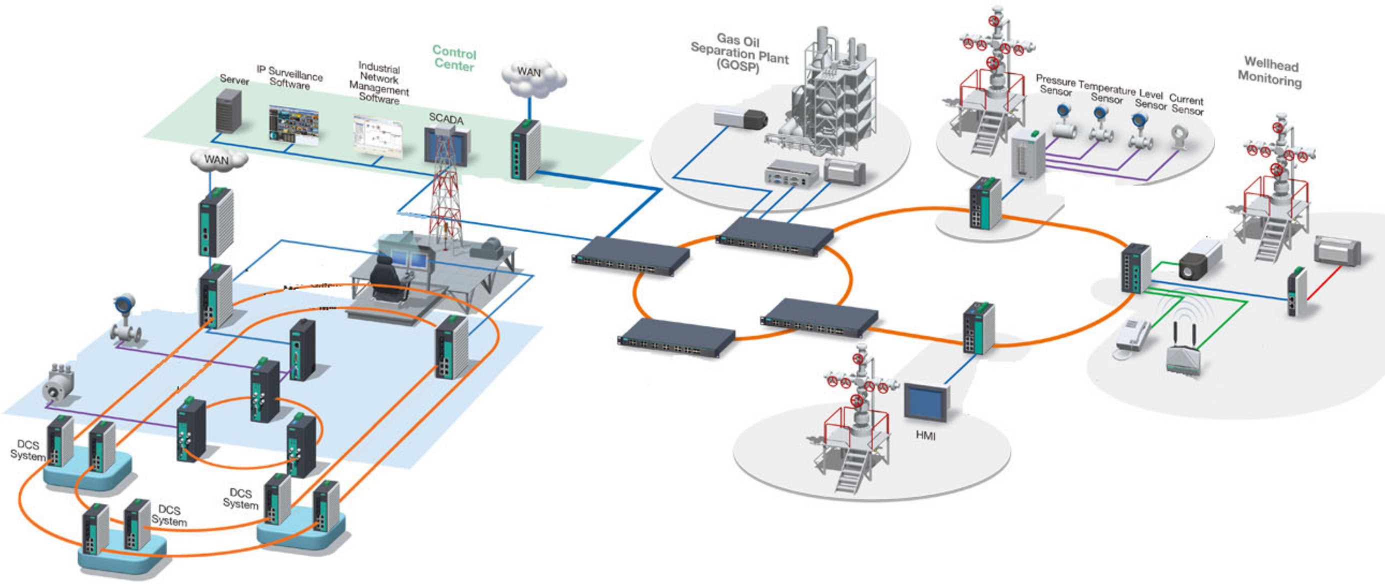
Before we look at what can be done quickly and economically in these remote energy industry facilities, it is good to make a brief review of what kinds of equipment and systems are present in these facilities. The next sections of this section will review a range of some of these types of facilities:

- Wellhead Facilities;
- Unmanned Offshore Production Platforms;
- Gas Plants;
- Solar Farms;
- Wind Farms;
- Distributed Power Plants.

As will be seen, there is a good similarity in the integral operating systems, especially the safety and control systems, which could be well managed with a remote operating centre (ROC). After looking at these facilities, we will review what capability should be present in these ROC's.

Wellhead Facilities

Typical remote oil and gas wellsites could have wellheads, separators, metering package, line heaters, relief systems with flare, utilities building (with communications), and chemical tanks and pumps. This kind of remote facility is typically unmanned. There would be periodic site visits by maintenance personnel.



Reliability of the safety and control systems is essential – this facility has live hydrocarbon fluids under pressure coming to the surface and there would be safety and environmental risks to be properly managed. With the remote nature of the facility, these systems might encounter conditions requiring a shutdown (e.g. trips) and then operating or maintenance personnel might have to visit the facility to see what needed adjustment or intervention. It is most often something routine and not a material incident but an abundance of caution would be required in order to ensure integrity and demonstrate to stakeholders including regulators that the necessary safety was being delivered. Instruments routinely drift and fail, valve actuators may fail to perform as specified, and communications can fail - the safety and control systems would have to respond in case something more significant was happening.

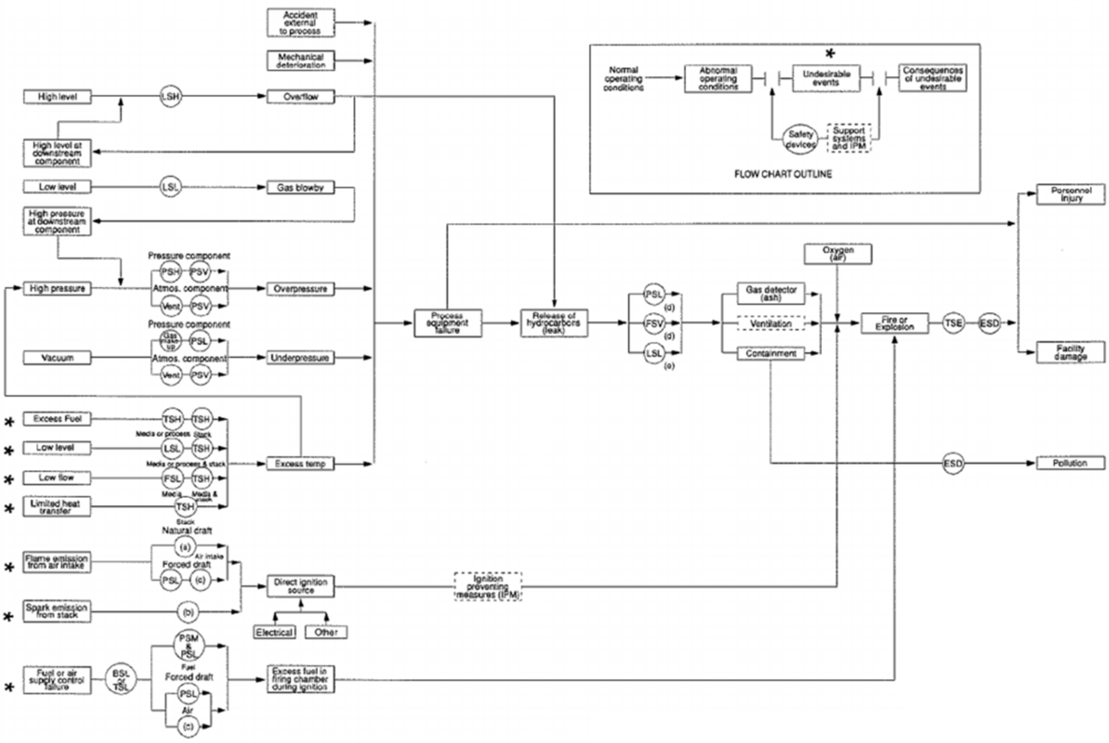
The amount of instrumentation is an technical decision to ensure sufficient detection of potential problems across the facility, how much redundancy is needed, and frequency of required maintenance. An important goal is to limit unplanned maintenance. Digital transformation can involve physical as well as virtual instruments and multiple communication paths (i.e. wired and wireless, parallel and serial buses, controllers and switchovers). Correct selection and specification of IoT devices and system architecture is needed with digital transformation tools like data analytics and remote monitoring and diagnostics. Due to the typical unmanned nature of the facility, best practice remote monitoring should include visual / infrared camera and audio monitoring with analytics to help rapidly detect anomalies including potential hydrocarbon releases or intruders.

Unmanned Offshore Production Platforms

Typical unmanned offshore wellhead platforms could have wellheads, separators, metering package, heaters, relief systems with vent or flare, utilities (including communications), and chemical systems. This kind of remote facility is widespread around the world in shallow water, especially with smaller hydrocarbon accumulations. There would be periodic site visits by maintenance personnel. Two unmanned platform examples are pictured below:


Equinor worked with Honeywell for a much larger "normally unmanned" platform at Valemon, offshore Norway, which is about 160km west of Bergen. There is an onshore control room at Sandsli which utilises 150 cameras located on the platform. Data comes from through DCS network as well as additional wireless sensors for machine monitoring. Vibration and other equipment monitoring devices from Bently Nevada are used to gather more data from pumps and compressors to assist the remote operators. Instrumentation makes use of "auto device commissioning" to recommission or recalibrate instruments remotely using either Foundation Fieldbus (FF) or HART/WirelessHART depending on the particular type of instrument. An independent safety shutdown system was provided through HIMA devices. These systems have allowed the remote platform to be unmanned 4 weeks out of 6, with maintenance being performed on the other 2 weeks. Maintenance campaigns are planned with the necessary technical competences, procedures, safety checks, isolations, tools, and spare parts prepared and ready for use. This type of remote facility operations is applicable to multiple types of energy industry facilities.

Safety and control systems have to be rigorously designed, tested, and operated to ensure regulatory requirements are met to ensure safety and environmental considerations are satisfied. Potential hydrocarbon releases could rapidly result in safety risk to the facility integrity and / or uncontrolled emissions into the environment. Safety systems are required and need to be remotely monitored (e.g. API RP-14C safety flow chart example below):

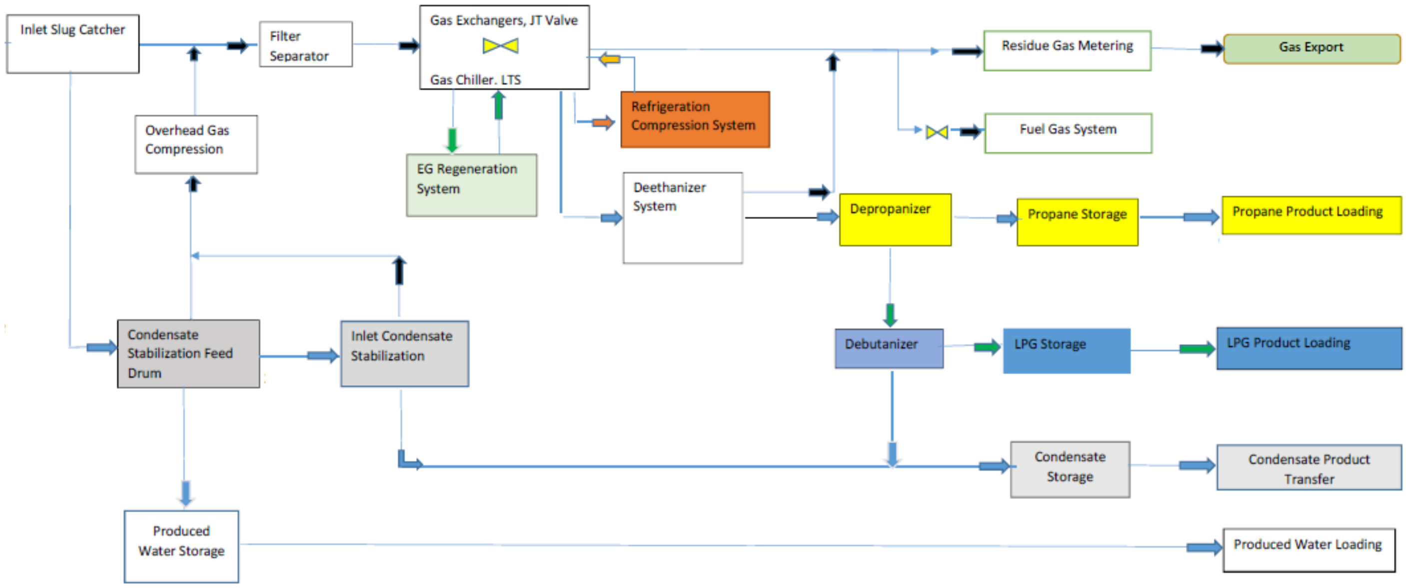


The objectives of these safety and control systems are to prevent undesirable events that could lead to a release of hydrocarbons; shut in the part of the process responsible to stop the release; accumulate and recover (liquids) or safely disperse (gas) releases; prevent ignition of any releases; shut in the process in case of fire; and restrict the spread of impacts to other facility systems. Remote operators need confidence that the facility systems can do this, but also have the ability to remotely monitor to assure the continuous integrity of the facility systems.

Gas Plants

A remote gas plant could have process trains with inlet separation, compression, sweetening, refrigeration, liquid fractionation and stabilization, power generation, storage, and export facilities. This kind of remote facility is likely going to have some amount of minimal manning due to the complexity of the facility, but we can ensure they are properly supported for operations and maintenance. Reduced manning is possible and the main function of field teams should be to conduct maintenance.

Plant systems would include safety & control systems, fire & gas, SCADA, metering, gas treatment, separation, fractionation, compression, instrumentation, and relief systems. Depending on the subsurface reservoir fluid properties and resultant plant product mix, this kind of facility could range in complexity and therefore ease or difficulty of operation and maintenance. A key to reducing costs is to improve the efficiency of the operations by reducing the field manning requirements whilst maintaining the asset integrity.



Remote monitoring with virtual rounds is possible so that smaller field teams can concentrate on maintenance.

Multi-skilled, multi-discipline field teams should be used to help reduce manning. Remote technical experts (in asset teams or in vendor teams) can be connected with the small field teams to provide specialist support to help diagnose any issues and perform complicated maintenance. The goal would be to augment the smaller field teams with remote expertise (who can then support multiple field facilities).

Solar Farms

A remote solar panel farm would have arrays of photovoltaic panels on elevated supports, buried cabling, access tracks, security fencing/lighting, pole mounted PTZ cameras, substations with electrical switchgear, inverters and transformers.

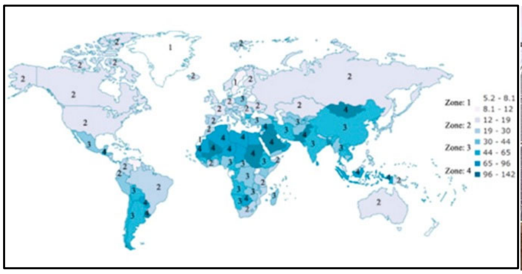
A DNO substation (or 'transfer station') would be present to regulate the electrical current flow of the solar farm and adjust the voltage using reactive power.

An underground AC cable would connect the solar farm to a DNO substation and then on to the Point of Connection (i.e. to the electricity distribution network).

Some solar farms will have Energy Buffer Units (EBU) providing storage of surplus electricity. Some of these types of units have a storage capacity of ~2 MWH/each 40 foot container.

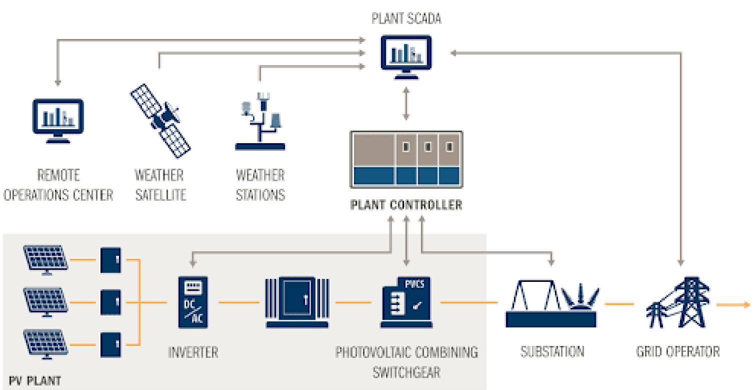
Security is particularly important due to electricity safety risks and security of supply to power utilities.

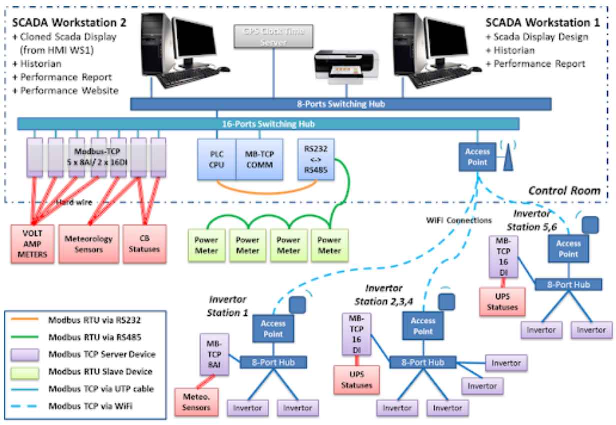
Besides electrical systems maintenance, these panels may need periodic cleaning (especially in dust prone areas). Autonomous robotic panel cleaning is possible and remote monitoring will ensure correctly done:



Ground maintenance (which could be autonomous robots as shown below) may need to be done:

Safety and control systems are used to ensure reliable performance and satisfy the requirements of the grid operators. Sections of the panel arrays would be switched on and off as needed for electrical demand or maintenance. Electric components will have IoT devices to monitor their performance and integrity.

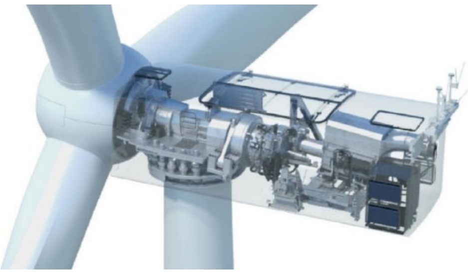
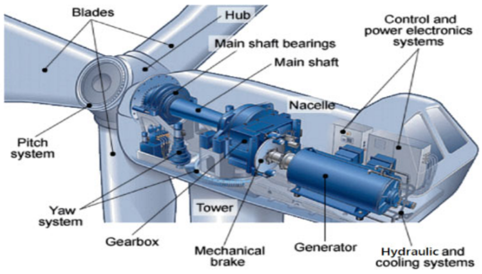




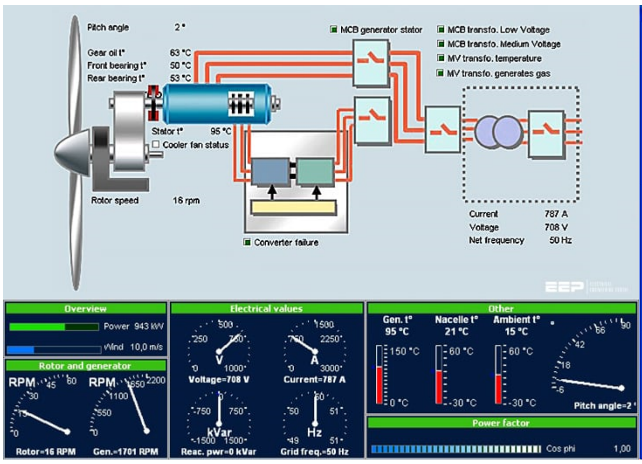
Wind Farms

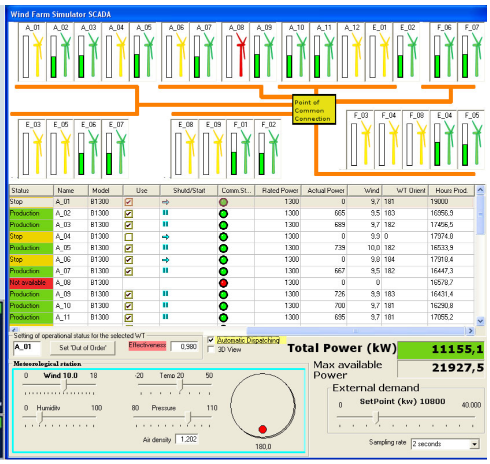
A remote wind farm would have a number of wind turbine towers with multiple blades connected together on a shaft linked to mechanical equipment inside a nacelle. Additional equipment would be located in ground level facilities. Electrical power gathering systems would connect these individual elements together and, after transforming, to the public electrical grid.


Maintenance inside the nacelle would include shaft, gearbox, generator, yaw motors, and sensors. Electrical systems are monitored, rotating equipment is monitored, and blade positions and pitch monitoring. Sensors on each turbine would send equipment and environmental data back to a SCADA system. This data would include information on lubrication levels, vibration, temperatures, and foundation displacement to help plan maintenance. For instance, if the wind eddy sensors show too much vibration in the turbine shaft, it could indicate the shaft had run too far out of place and needed to be realigned. Lubrication checks are critical maintenance activities.

Substations would have switchgear, power protection systems and the electric meters. Transformers may be part of the substation components to enable step up or step down of the power output. Cabling integrity needs to be checked and maintained. Power generated on each turbine (~600-1000V) is transformed (voltage stepped up) and transmitted to the wind farm substations. The cable networks would usually run at a medium voltage (11-36kV).

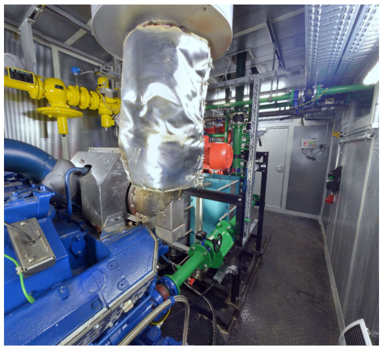




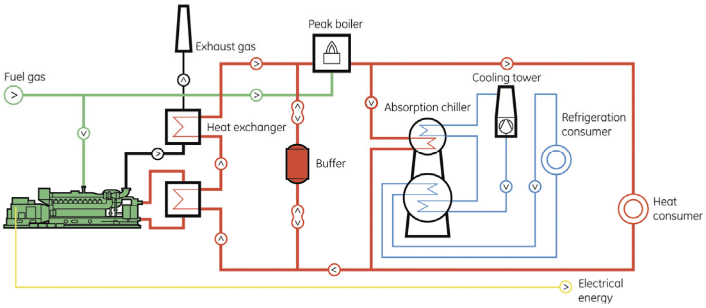
Distributed Power Plants

A good example of small scale distributed power plants are Cogeneration Power Plants which could have (1) a gas engine to drive the generator; (2) generator for power production; (3) heat exchanger system for the recovery of heat energy from exhaust, engine waste heat and oil circuits; (4) electrical switching and control equipment for power distribution and engine management; and (5) hydraulic installations for heat distribution. They are sized to support infrastructure projects, retail facilities, industrial plants, mining facilities, etc. Sometimes their electrical output is exclusive use for an industrial development and sometimes it is fed back into the public grid.

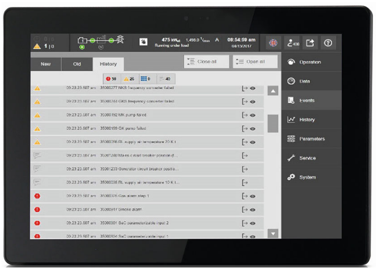
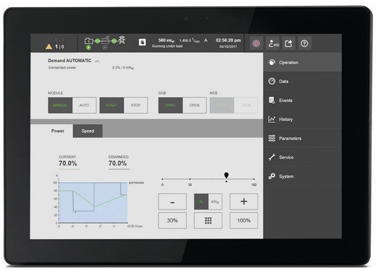




The example[48] shown in these photographs is a modular cogeneration power plant with fuel systems, engine, genset, air intake and exhaust systems, and control systems. Multiple fuels are possible from biomass to more conventional hydrocarbons. Biomass fuelled distributed power plants are environmentally attractive consumers of farm slurry, farmyard manure, and plant-derived biomass material (e.g. maize silage). Other versions use industrial fats, landfill gas or natural gas.



Safety and control management systems are typically available (local and remote). A networked SCADA system allows increased visualization and control options. All data could be displayed including genset control data and data for coolers, ventilation, and lubricant supply. Historical data for voltage, current, frequency, active and reactive power would allow remote monitoring and diagnostics. Alarm systems would provide notifications, alerts and alarms[49]. Healthcare contracts would allow this data to be analysed by supplier personnel to provide operational and maintenance support to the remote operating team.

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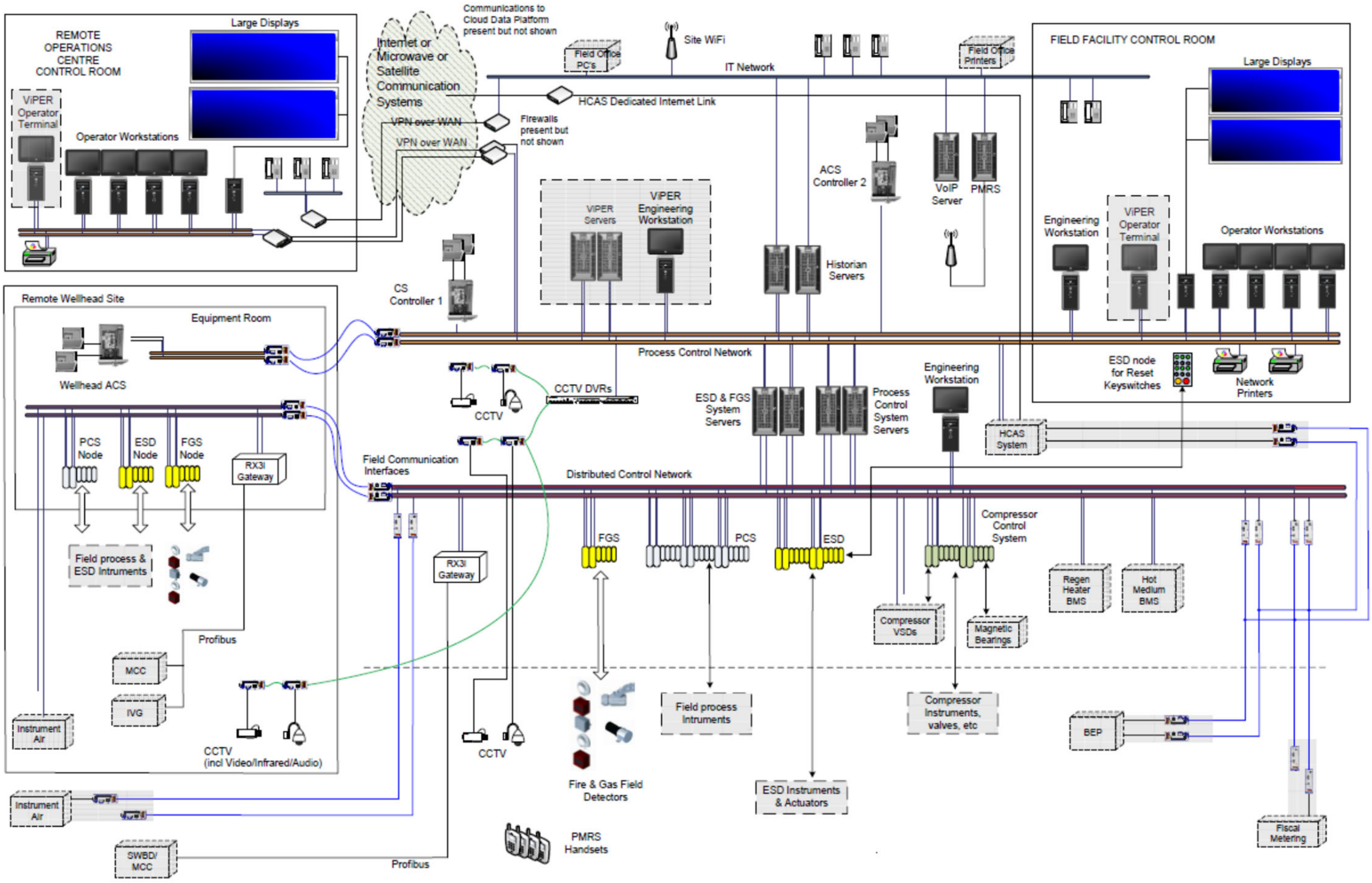
48 https://www.mwm.net/mwm-chp-gas-engines-gensets-cogeneration/distributed-power-plants/container-cogeneration-plant/

49 https://www.mwm.net/mwm-chp-gas-engines-gensets-cogeneration/distributed-power-plants/system-solutions/gas-engine-control-mwm-scada/

Common Elements of Remote Operations

A typical remote operations control systems architecture is shown below (modified slightly from a very good *Servelec Controls* example[50]). Several common control elements are readily apparent in this illustration:



The example shown is for a remote oil and gas process facility with separate remote wellhead sites. It could very easily be representative for other energy industry remote facilities with obvious industry specific changes to the field processes and equipment. Field IoT devices would gather data on operations to allow remote monitoring and diagnostics of equipment and functional systems in addition to the normal safety and control systems.

Remote Operations Centres

A key part of reducing the operating and maintenance costs of remote energy industry facilities is to have a good centralised operating centre. Field manning should be able to be reduced without risking the facility integrity assurance with the right types of safety and control systems architecture to allow remote operations from a centralised operating centre (which could then be monitoring and controlling multiple remote field facilities).

For some energy industry assets, there is no such centre, so the field operations are currently communicated back through voice, emails, and some kind of dashboard system (or sometimes even manual hardcopy reports). In other cases there may be a remote monitoring capability to receive some types of field data (e.g. *OSIsoft PI*) but not any control capability.

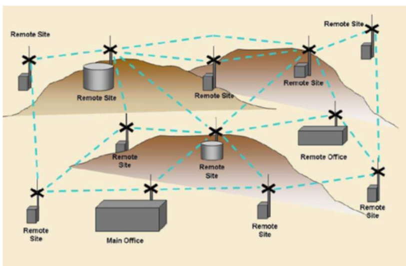
[50] https://www.serveleccontrols.com/servelec-controls/solutions/integrated-control-and-safety-systems/

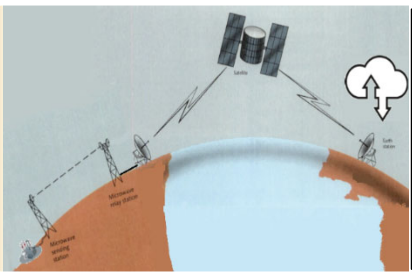
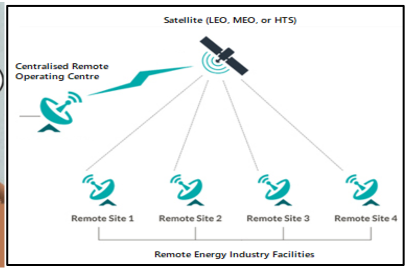
What is needed is more capability to gather the field data into a Cloud Data Platform, then allow multiple remote users to access this field data, perform diagnostics and analytics, obtain insights and make decisions, then remotely implement certain changes to field facility operating settings to optimise outputs and minimise unexpected maintenance issues. If there is any sensitivity to completely remote operations, certain operations could be allowed with the main function being remote monitoring and diagnostics

The cost of a centralised operating centre should be mitigated by the presence of certain pre-existing systems. Field facilities will already have safety and control systems typically installed inside equipment or control room buildings. These safety and control systems include software installed on computer hardware. The data flows in these systems needs to be leveraged from these locations to a more central operating centre. The technology and tools to do this are readily available. The centralised operating centre can effectively mirror the same kinds of workstations and software systems already present in the field control rooms. As shown in the photograph at the end of this section, these centralised operating centre control rooms can be fairly simple once we have good communications systems and links to the Cloud Data Platform. And the proximity of asset teams to the remote operators will be very beneficial to better cooperation and efficiency.

There would already be some kind of communications in place to allow the remote operating teams to be connected to the asset teams located in these centralised locations. These communication systems need to be evaluated to see what kind of bandwidth and latency is existing (and ensure upgraded cybersecurity):

- Hardwired (copper or fibre optic) systems will typically have a lot of potential to be increased in bandwidth;
- Wireless, mobile communication systems (i.e. radio, cellular) are improving with rapid advancement of availability with higher bandwidth and reduced latency – and the competition is making these advances at the same time as costs are reducing;
- Microwave systems (needed in some areas to connect field locations to better connected communication infrastructure including satellite earth stations) have high bandwidth and low latency capabilities;
- Satellite communication systems have been rapidly changing so that older VSAT systems may need to be upgraded to get the bandwidth and latency required, but the good news is that competition means this may be at the same annual cost.



Communication capability is essential to remove (or reduce) field personnel and replace them with centralised operating personnel within the asset teams. The ideal scenario is to minimise field personnel other than routine maintenance team visits or maintenance campaigns. Once the communications are in place, we have potential remote monitoring tools like autonomous drones or surface robots, cameras (video/ infrared/audio), and a wide range of IoT devices and sensors to help monitor not just safety and control, but also potential integrity issues.

Where field facilities are very complex, we need to support smaller field teams by augmenting their capability with digital transformation tools and workflows. Previous sections have described how access to data is key. Over the life cycle of an asset there are considerable amounts of data from engineering, procurement, construction, operations, and maintenance. This data helps operations and maintenance personnel to better operate and maintain equipment. This data should include Digital Twins which are virtual representations of the physical facilities. By numerically simulating the facilities and comparing physical IoT data with predicted values, we can identify where data analytics can help understand potential integrity issues (e.g. equipment degradation). This knowledge allows better proactive adjustment to operating settings and predicting preventative maintenance needs.

In all types of energy industry remote facilities, the aspiration is to reduce routine, time consuming tasks currently performed by expensive field workers and replace this with more remote control, monitoring, diagnostics, and better coordination with asset teams. The presence of field teams should be limited to maintenance unless a particularly complex or risky operation requires the presence of field operators. Companies will be challenged to modify their workflows and organisational cultures to successfully accommodate these digital transformation solutions. Smaller, multi-discipline, agile asset teams linked to the remote operators will facilitate better analytics and quicker identification of insights and necessary decisions to deliver increased value from these facilities.
We call this aspirational outcome **Integrated Intelligent Operations & Production**.

Acknowledgements

Thank-you to all those doing such good work with these technologies and tools and sharing the information so widely online. The advice on revised recommended workflows and needed organisational cultural changes should help many Energy Industry users better deploy these Digital Transformation solutions to their Remote Facility Developments. Energy Industries can support the Energy Transition drive to improve efficiencies by improving the operations of these Remote Facilities.