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Challenges of Digitalisation in the Offshore Oil and Gas Sector

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Challenges of Digitalisation in the Offshore Oil and Gas Sector

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As a sector, oil and gas (O&G) is slightly ahead of the architecture, engineering and construction (AEC) sector on the road to digitisation. This report attempts to capture the direction in which the upstream O&G, or "smart oilfield", sector is moving, and to identify some challenges that are likely to have parallels with the construction sector. Exploring how other sectors are meeting these challenges will shed some light on what the construction sector may face over the coming years.

First, an overview of some of the features of Digital or SMART OILFIELD will highlight similarities and differences between the two sectors. The bulk of the report highlights six challenges faced by O&G. As with buildings, transport and so on, much of O&G INFRASTRUCTURE IS AGING, which presents a challenge when deciding how to invest. This is compounded by the challenges created by MARKET FRAGMENTATION and the proliferation of different vendors and solutions. Standards are emerging from this environment, but fragmentation leads to issues of interoperability and DATA INTEGRATION as dozens of bespoke solutions prevent convergence on a single, sector-wide approach to digitalisation and makes it more difficult for the sector to learn collectively. Though this is a difficulty to be overcome in the digitalisation process, making these data more open and shareable actually leads to another challenge, CYBERSECURITY. The more reliant on data a sector is and the more widely shared data are, the more vulnerable to attack and the worse the consequences of breaches. While identifying specific technical solutions and standards is an important part of smart oilfields, a recurring challenge mentioned throughout the reports was the need to address HUMAN FACTORS, such as skilled, experienced personnel and a culture of data security, data collaboration and data-driven decision-making. Finally, firms need the financial capability and willingness to make the INVESTMENT in an integrated approach to data. There is a high degree of interdependency between these challenges and, while firms might focus investment on particular priorities, ignoring any one of these factors would be detrimental to the desired outcomes. The report concludes with a BIBLIOMETRIC OVERVIEW, including a discussion of the literature.

The key recommendations arising from this review are as follows:

- Have data frameworks in place that address the most appropriate solutions at all scales of the firm or sector, including standards, policies, workplace cultures and long-term digital strategies
- Modernise physical assets so that digital investments are not tacked on to a suboptimal legacy infrastructure
- Conduct threat and maturity assessments, take inventory
- Consider cybersecurity in the design of the information environment, including non-technical solutions such as staff training and culture

- Manage the transition to digital through training and communication
- Promote sharing of information across the company and across the sector in secure, integrated platforms
- Recruit staff who are knowledgeable in IIoT and cybersecurity as well as sector-specific concerns
- Make informed choices that balance interoperability of and access to data, modularity of systems, security and safety

What is a smart oilfield?

"An offshore oilfield can generate over 0.75 terabytes of data per week and a large refinery can deliver over one terabyte of data per day." (Technavio, 2017a)

The activities and technologies that define a smart oilfield centre on data, and specifically the ability to extract insights from data in order to aid decision-making and overcome the considerable challenges faced by offshore O&G. The following are potential goals of big data analysis in the offshore O&G sector:

- Improve personnel and environmental safety
- Maximise well productivity
- Monitor and maintain physical equipment
- Model real-time data from a variety of sources (including GIS and seismic data and flow, pressure and temperature measurements)
- Present an integrated view of all relevant information for decision-making
- Assess past performance to identify areas for improvement, predict likely outcomes
- Capture and share organisational knowledge
- Store and transmit data securely

Achieving these goals means investing in the Industrial Internet-of-Things (IIoT), a network of devices, rich data and people that communicates, analyses and makes decisions about the processes involved in an industry. This can improve efficiency, transparency and maintenance of equipment, reducing costly shutdowns (Technavio, 2016a).

Underpinning IIoT is Big Data, which is defined by its parameters of value, veracity, volume, velocity, variability, variety (Technavio, 2016b). Big Data analytics allows firms to integrate diverse, often dispersed data, measurements, and domains to derive insights that are not otherwise possible. The volume and variety of data generated by the O&G sector is likely to increase over time, especially as the potential for interoperability increases. With assets spread over the globe, the ability to bring together data that are both geographically and structurally varied and analyse them at a central point represents a clear opportunity to extract value. However, traditional data management applications are not sufficient to deal with the sheer quantity of the data involved, let alone to ensure data quality.

As with BIM, the O&G sector has discussed the progress toward digital adoption in terms of levels. According to Chevron's senior upstream advisor Trond Unneland:

"'Level one was when we increasingly put sensors everywhere to measure data in real time … The second level was when we integrated all of this data into models and we were able to get dashboards etc. The third level is when we started to do optimisation and predictive analytics. We've had fantastic results using advanced analytics and predictive analytics in our operation, and going forward we want to find new ways to extract information from the data we have acquired.' Unneland believes Chevron 'might be on the edge of a fourth level on this digital oilfield thanks to emerging technologies', which he said included mobile computing, the internet of things, 'and advanced analytics - and increasingly cognitive computing. We need to apply new ways to find correlation and insights to reach this level four of the digital oilfield…We are on the right path. We understand that data is just as much an asset as the physical structure and the oil in the ground, and we have efforts underway right now to improve quality of our data, to improve the governance and organizational capability.'" ('Vicki Harris - Manager, Cloud Center of Excellence and Programs, Chevron Corporation', 2017)

The barriers to digital maturity for this sector may be the same barriers faced by others following in their footsteps. Indeed, the O&G sector is looking to others for guidance as they lag behind defence, online retail and aerospace in adoption. Critics point to a sector-wide tendency toward conservatism, noting that much of the data that are collected remains untouched in the systems of those who generate them, rather than making their way to people responsible for operating the wells (Perrons & Jensen, 2015).

The potential parallels between O&G and a data-driven built environments are clear. One of the greatest difference, however, is the drivers for change in these sectors. In offshore O&G, big data management and analytics solutions are a response to challenges the sector is facing; increasingly challenging extraction conditions, the need for increased productivity of each well, a strict regulatory environment and the potential risk to productivity, human lives and the environment when equipment malfunctions or poor decisions are made. The need for digitalisation is clear, but managing this change throughout the sector will require addressing large-scale challenges efficiently and intelligently.

Challenges and solutions

Challenge 1: Aging infrastructure

"Typically, the digital thinking and narratives stop at data-driven insights. But to become a digital leader, a company should consider making a change in its physical world by modernizing its core assets." (Mittal, Slaughter, & Bansal, 2017)

O&G has an age problem with its physical assets. "More than two-third of the existing oil and gas pipeline infrastructure in the US dates back to 1970" according to Technavio (2017b). The sector has already invested in digital solutions to increase well productivity, but the physical assets, plants and equipment have not received such attention. The benefits on production optimisation of being able to analyse and synthesise real-time data would considerable, but aging assets pose a barrier to reaching this state.

Mittal et al. (2017) estimate that a 1% gain in productivity from these assets – by investing in intelligent automation for safety and maintenance, and on-demand, on-site manufacturing of parts – could save the sector about $40 billion annually. The included figure from Mittal et al. (2017) shows some use cases for digital technology to aid the physical infrastructure. Updating physical assets could solve some of the major difficulties the sector faces, such as operating in risky environments and costly downtime for maintenance.

Solutions to aging infrastructure

Possible solutions include robotics, onsite manufacture and use of a digital twin as a living model of an asset. This would help monitor for safety and function, and predict performance and maintenance. Replacing legacy physical infrastructure with infrastructure that is made to enable smart technology would involve a high up-front investment, but have the potential to save money long-term. Cybersecurity should be integral to this process, or automated systems and digital asset models will be vulnerable to attack. Similarly, data integration should be a consideration. Adding more sensors would be a fruitless endeavour if the data they generate cannot be analysed alongside other forms of O&G data.

Solutions to market fragmentation

Consolidation of the industrial IT market is forecast for the next five years, with leaders and strong followers emerging and bundled hardware and software becoming more prevalent (Technavio, 2016b). However, waiting for a market-based solution may not be the wisest move. The needs of downhole O&G are not being met by waiting for vendors to deliver solutions based on what other industries need (Buchan, 2017). If the O&G sector is waiting on the data management market to deliver the right solution for its specific needs, organisations might invest in the wrong technology or fall behind competitors waiting for someone else to solve the problem.

Perrons & Hems (2013) suggest that modular IT architectures are a useful way forward. Rather than investing in whole software packages that are soon outdated and need wholesale upgrading or replacement, firms could develop or buy web-based applications to achieve particular needs. These could be changed and updated as needed with relatively little expense.

Challenge 3: Data integration

"Oil and gas data was never designed to be integrated, so for example information from a rig may not be compatible with information from an ERP system. This does not always mean the oil and gas industry faces an information quality issue, rather this is an information design issue. So oil and gas firms have to re-design how they govern, store, and manage their data so it can be integrated to support Digital Oilfields." ('Cybersecurity is a major challenge for the region', 2017)

Table 1. Industry examples of firms digitizing their physical assets

Stages	Examples	Opportunity areas
Robotize	**PROBLEM** **Tough, riskier operating environment in offshore locations** **SOLUTION** **Robotization of platforms** Woodside Petroleum is combining its cognitive science technology with NASA's humanoid robotic system, R2C3, one of the three humanoid robots developed by the space agency and General Motors, to ultimately design offshore facilities for robot-only interventions and operations. Woodside will begin by researching ways in which the robonaut could perform tasks from more than 300 ideas suggested by the company's operators, engineers, and maintenance workers.[46] "(It's about) using robotic platform sensor technology to detect and look for errors in the plant well before they become an issue and a robot platform will assist in that," says Shaun Gregory, Woodside senior vice-president and chief technology officer.[47]	• Rigs and platforms • FPSOs • Underwater installations
Craft	**PROBLEM** **Reducing downtime and optimizing supply chain for stand-alone parts** **SOLUTION** **Laser scanning and 3D printing** BHGE is working to reduce downtime and optimize supply chain associated with the sourcing of complex, customized parts such as production pump impellers. The company would run a laser scan on every part of the impeller to create a 3D model that acts as a digital stock. Using the model, it would then employ an advanced 3D printing metal fabrication technology called direct metal laser sintering (DMLS) to print impellers, in just 10 days as compared to about three months required by traditional methods.[48] Although the near-term utility of this innovation is to manufacture critical parts quickly and precisely, the digital stocks, when combined with analytics, open up new avenues in design-material thinking and optimizing operations.[49]	• Offshore risers • Gas nozzles • Sand screens • Subsea injection tools • Downhole cleanout tool nozzle • Drill bits • Perforated pup joints • Liner hanger spikes
Virtualize	**PROBLEM** **Maintaining structural integrity of long-lived offshore assets** **SOLUTION** **Living model of the physical asset (digital twin)** A joint industry project (JIP) led by Akselos and LICengineering is helping Shell to advance its offshore structure integrity by combining structural simulations (or digital twins) with sensor data on rigs and big data analytics in the cloud. Data from sensors on a platform capturing information on corrosion, hull damage, strain, wind and sea states, etc., would be incorporated real time in the digital twin using cloud-based solvers.[50] By running thousands of simulations on the updated digital twin, the company would not only help its engineers execute an appropriate response immediately but also prototype new and lean structural designs.	• Rigs and platforms • FPSOs • Ships and vessels • LNG facilities • Subsea equipment

Source: Deloitte analysis. **Deloitte Insights | Deloitte.com/Insights**

Figure 1 - Source: Mittal et al. (2017). Used with permission.

Interoperability and integration of data is a key challenge for any sector moving toward digitalisation and O&G is no exception (Technavio, 2017a). Just as the IT market is fragmented, O&G data are derived from different sources, exist in incompatible formats and growing at a rate with which it is difficult to keep pace. Some data sources are geographically dispersed, or held in repositories with different standards for data description, while data from sensors will vary widely in structure and frequency. Priorities for and demands of data also vary within the sector, for example between the operator needing to know about progress, daily cost and a host of other details, and the rig contractor whose chief concern is how the rig is functioning. Finally, the data must meet the sector's performance requirements for reliability, latency, security, and bandwidth (Technavio, 2015) and allow for rapid decision-making. Ideally, all of this would be done with little loss of productivity, but in reality, "the upstream oil and gas industry loses up to $8 billion per year in non-productive time (NPT) as the engineers spend 70% of their time searching for and manipulating the available data" (Technavio, 2016b).

Assuming that data are eventually integrated, the next challenge is extracting valuable insights. While human analysis of Big Data can help decision-makers, the next level involves cognitive technology that would "learn" from past data and make reliable decisions automatically. While there are multiple academic and industry-led projects working on advanced analytics and cognitive computing – what Chevron describes as "Level 4" – they are not yet fully developed.

Solutions to data integration

However, these projects do look promising. Repsol have partnered with IBM to develop cognitive technology that should, by the end of its third year, be intelligent enough to optimise oilfield acquisition. Apache Corporation have deployed predictive analytics to identify the cause of mechanical failure that lost them 10,000 barrels per day. The data gathered from across the industry helped them identify 40 actions they used to reduce unplanned downtime and cut losses. (World Economic Forum & Accenture, 2017)

Cloud computing has potential to help with data integration. Storing data centrally can reduce the insularity of data structures and facilitate access. Instead of having to take a variety of routes to access data stored in different formats and locations, some of which may experience reliability issues, cloud storage allows for a smoother, more reliable service. Gathering data in a single "data well" or "data vault" leads to a single point of vulnerability, which is a concern for cybersecurity. Therefore, "companies need sophisticated data storage, management, cleansing, and filtering of data" into a single asset data model (Technavio, 2015c). This may take the form of a federated database, where data are stored separately, but called up by a single, overlaid linked data structure. There are also private or hybrid cloud storage options that compromise between security and accessibility of data for those who need it.

However, it could be argued that the public cloud may actually be safer than private services that do not specialise, as public cloud operators are focused on the security and reliability of their services. Various sectors use the public cloud, including healthcare services and online retail, despite the need for secure storage of personal data. Those sectors found "some kind of technological solution or a shift in the underpinning market conditions, and then each organization successfully moved mission-critical data and functions into the public cloud" (Perrons & Hems, 2013).

Challenge 4: Cybersecurity

"Operation systems close to drilling and well site operations such as sensors and programmable logic controllers are intended to perform tasks with 24x7 availability as their primary attribute... In contrast, IT systems such as enterprise resource planning have a reverse priority order of confidentiality, integrity, and availability. This clash of objectives—safety versus security—plays out in drilling and production control rooms where engineers fear that stringent IT security measures could introduce unacceptable latency into time-critical control systems, impacting decision making and operational response." (Deloitte Insights, 2018)

O&G relies on the security of high quality data for competitive advantage, but as the opportunity to analyse previously disparate data leads to greater interoperability and sharing, the sector faces greater risk of breaches. Outcomes of a security breach could include lost revenue due to shut down, loss of competitive advantage with leaks of proprietary data, disruption of essential services and serious incidents that threaten worker safety and the environment. Currently the security concerns of upstream O&G are primarily physical assets rather than information, so upstream data is considered particularly vulnerable (Technavio, 2016a).

The current maturity of cybersecurity in O&G is moving toward a systematic framework of practice, including clearly defined processes and established security functions (Deloitte Insights, 2017). Despite this, 50 O&G companies in Europe fell victim to a sophisticated phishing and Trojan horse campaign in 2014 (Deloitte Insights, 2018). Attacks may include phishing, distributed denial of service attacks and internal threats (Technavio, 2017a). The risks are compounded because difficulty in identifying the sources of breaches can lead to data remaining unprotected for days.

Solutions to cybersecurity

The solution, then, is to provide the right type of security for each area of the organisation, matching the priorities and likely threats to appropriate measures, including digital security (e.g. encryption), regulations, standards, access control (e.g. authentication), physical security and staff training. This is known as "defence-in-depth" ('Cyber security', n.d.). Similarly, investment should prioritise the areas with the highest vulnerability to attack and worst consequences to attack. In the case of offshore O&G, an attack on the real-time monitoring systems at the production point could lead to loss of human life and environmental catastrophe, so the priority would be to secure those systems as robustly as possible.

The World Economic Forum (2017) notes that the regulatory environment is currently lagging behind the digital world, with intellectual property (IP) protection not suited to data sharing along value chains. A legal framework is needed that supports data sharing while ensuring that stakeholders feel secure that their IP will be protected. However, (R.K. Perrons & Richards, 2013) warn that over-regulation, particularly in response to devastating incidents like Deepwater Horizon, may prevent O&G from learning lessons that other sectors, such as aerospace, have to teach.

While there are several international standards that cover cybersecurity for industries such as O&G, Mayer et al. (2013) mention that standards alone are not sufficient to meet the large scale interoperability problem. They highlight the need for a layered ontology such that stakeholder needs at various scales are all represented. A multi-sector group called MIMOSA is working on an interoperability standard called OIIE, "a supplier-neutral, industrial interoperability ecosystem" ('Open Industrial Interoperability Ecosystem (OIIE) | MIMOSA', n.d.). Such a standard, if adopted across sectors, would go a long way to defining standards that would encourage interoperability and security of data.

There is no "one-size-fits-all" cybersecurity solution in O&G. Rather, it should be based on an organisational framework that assesses the risks and meets them with appropriate solutions, whether those are software, hardware or human-based. However, there should be a drive to improve the standard of security toward automated, predictive security threat detection and would feature standards-based industrial control systems, authentication for access management, mobile and end-point security, threat intelligence/sensing, data loss prevention and behavioural analytics (Deloitte Insights, 2017). The graphic below, from Deloitte Insights (2018), demonstrates the range of security measures that can be deployed, including means of addressing attacks once they happen.

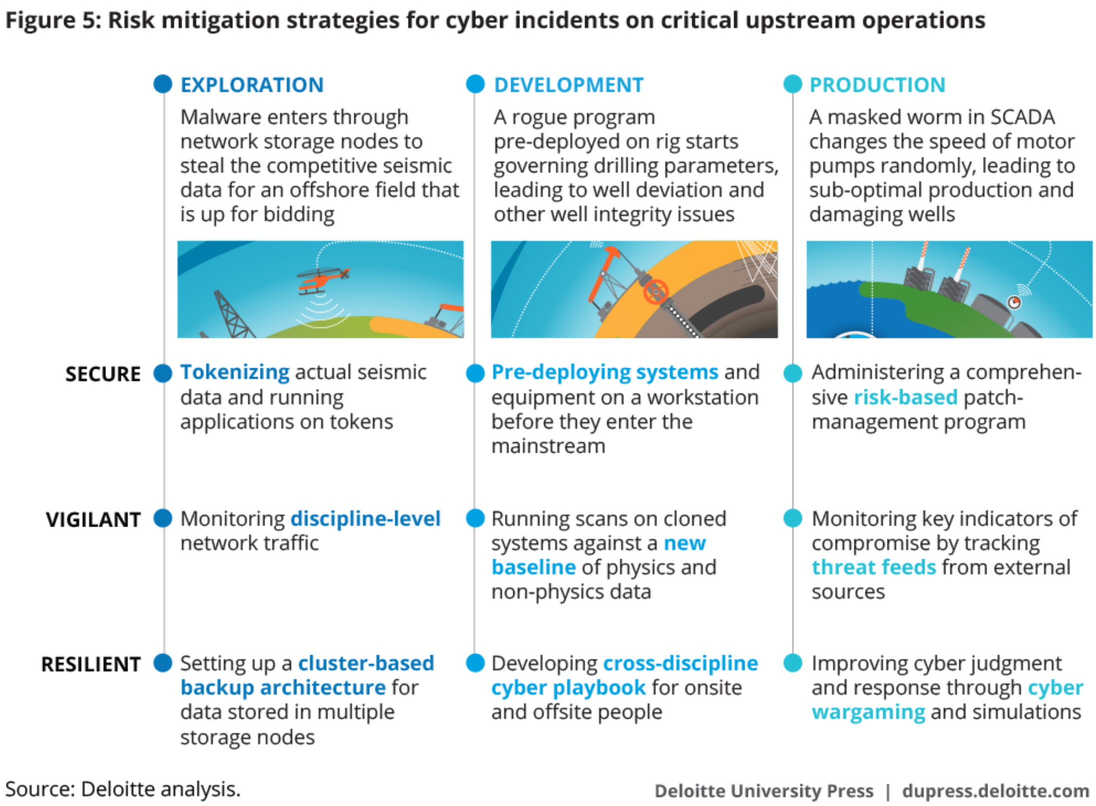


Figure 2 - Source: Deloitte Insights (2018). Used with permission.

Some key solutions identified by Deloitte Insights (2017) and World Economic Forum & Accenture (2017) include:

- Policy and standards
- Risk assessment
- Training and awareness

- Vendor management
- Information protection and encryption
- Identity management
- Network segmentation
- Physical security
- Malware and patch management
- 24/7 incident monitoring
- Threat intelligence
- Emergency and incident plan (resilience)
- A single line of accountability
- Global data standards related to sharing, security and transparency

Challenge 5: Human factors

"Actually realising the benefits of [digital oilfield] technologies isn't as simple as setting up a wireless sensor network and pushing the 'on' button. The level of data management and analytics required for successful [digital oilfield] deployment is still unfamiliar territory for large sections of the industry – especially veteran engineers more accustomed to hard graft than smart tech and the Internet of Things – so the human factor can be a significant pitfall." (Lo, 2014)

While identifying specific technical solutions and standards is an important part of developing smart oilfields, a recurring challenge mentioned throughout the reports was the need for skilled, experienced personnel to foster a culture of data security, data collaboration and data-driven decision-making. Without the organisational culture and skills to support smart oilfields, no amount of infrastructure, integration or security provision will suffice. The key to adoption is investment in skills, and the failure to do so can result in money wasted on unsuccessful digital initiatives. "There is a high possibility regarding the failure of implementation if the big data project team lacks experience." (Technavio, 2016b) It is not enough to buy black box analytic tools. The expertise to know what to measure, where the vulnerabilities are and what to do in case of a breach should exist within the organisation.

Throughout the sector there is a lack of understanding about the nature of data and a failure to consider data as an asset (Technavio, 2016b; Perrons & Jensen, 2015). According to a 2013 survey at the SPE Intelligent Energy International event, 60% of O&G industry experts "viewed resistance to change as the biggest challenge to realizing the full potential of smart oilfield technologies." (Technavio, 2016b) The industry as a whole tends toward the conservative, fearing the "fail fast" mentality of more agile sectors. The resistance to automation has led to many local work-arounds, and at the operational level many employees are sceptical of technology (World Economic Forum & Accenture, 2017). This means that in order to be effective, a culture change is necessary before adopting smart oilfields.

The final human factor that poses a challenge to digitalisation in O&G is the lack of organisational knowledge management. Existing knowledge is not shared within organisations and therefore cannot be leveraged to learn from past mistakes or share previous routes to success. This prevents organisations from learning from their own experience (Technavio, 2016b). If this data can be captured and disseminated, it would be a valuable asset.

Solutions to human factors

The primary way to overcome the skills gap and the challenge of cultural change is to recruit for this need. A new type of employee is needed that simultaneously understands the O&G context and also "understands analytics, information technologies (IT), and mathematics while also having the ability to communicate effectively with decision-makers." (Perrons & Jensen, 2015). New roles with enticing career trajectories and recognition programmes will help with recruitment of people with the engineering and data science skills needed in this sector (Matson & Krome, 2007). Industry leaders have already recognised the human factors as a key ingredient in this transitional period. The CIO of Chevron, Bill Braun, states that the company is starting to build data and IIoT expertise by prioritising it at recruitment ('Vicki Harris - Manager, Cloud Center of Excellence and Programs, Chevron Corporation', 2017). However, if these skills are not developed at University (and earlier), the sector will not have the talent pool to draw from.

Key solutions recommended by Lo (2014), World Economic Forum & Accenture (2017) and Deloitte Insights (2017) include:

- Offer internal training and communication for change management
- Offer industry-wide training, e.g. Digital Oilfield Training Services (DOTS)
- Encourage Universities to focus on developing data modelling and analysis skills alongside traditional engineering skills
- Make the sector seem appealing with an appealing career path for digitally savvy staff and recruit people who understand the importance of secure, interoperable data
- Put policies and procedures in place that support organisational learning, including process management to analyse success of solutions
- Engage senior executives in developing a digital strategy roadmap
- Drive a culture of innovation and technology adoption with digitally-enabled multidisciplinary teams and collaborations with the wider sector
- Build digital capabilities through investment and partnership

Challenge 6: Investment

"The enterprises that remain oblivious to the potential of data analysis are unable to compete in the current business environment as the established market leaders, and new entrants are likely to use big data solutions to compete against them." (Technavio, 2016b)

Finally, investment in the infrastructure, security and personnel that underpin smart oilfields is essential, but may be the biggest hurdle to adoption. The hardware, software and the expertise to manage them do not come cheap. However, the advantages of adoption and disadvantages of being left behind will potentially drive investment (Technavio, 2017a). As each of the previous sections has shown, there are long term advantages to up-front investment in data infrastructure, IIoT technology, learning systems, "defence-in-depth" and a skilled workforce.

Key solutions

The challenges outlined in this report are interdependent and require integrated solutions. Ershaghi & Omoregie (2005) offer a vision of this integration, noting that success in the future "requires significant improvements in data management, better integration of technical applications across different disciplines and wider breadth in the technical knowledge of the asset management teams (technical and operational). The vision also includes more collaborative problem solving and decision making by the technical professionals."

In order to implement smart oilfields and get the most out of IIoT investment, analyses of the O&G sector demonstrate the need to:

- Have data frameworks in place that address the most appropriate solutions at all scales of the firm or sector, including standards, policies, workplace cultures and long-term digital strategies
- Modernise physical assets so that digital investments are not tacked on to a suboptimal legacy infrastructure
- Conduct threat and maturity assessments, take inventory
- Consider cybersecurity in the design of the information environment, including non-technical solutions such as staff training and culture
- Manage the transition to digital through training and communication
- Promote sharing of information across the company and across the sector in secure, integrated platforms
- Recruit staff who are knowledgeable in IIoT and cybersecurity as well as sector-specific concerns
- Make informed choices that balance interoperability of and access to data, modularity of systems, security and safety

Bibliometrics

Overview of the literature

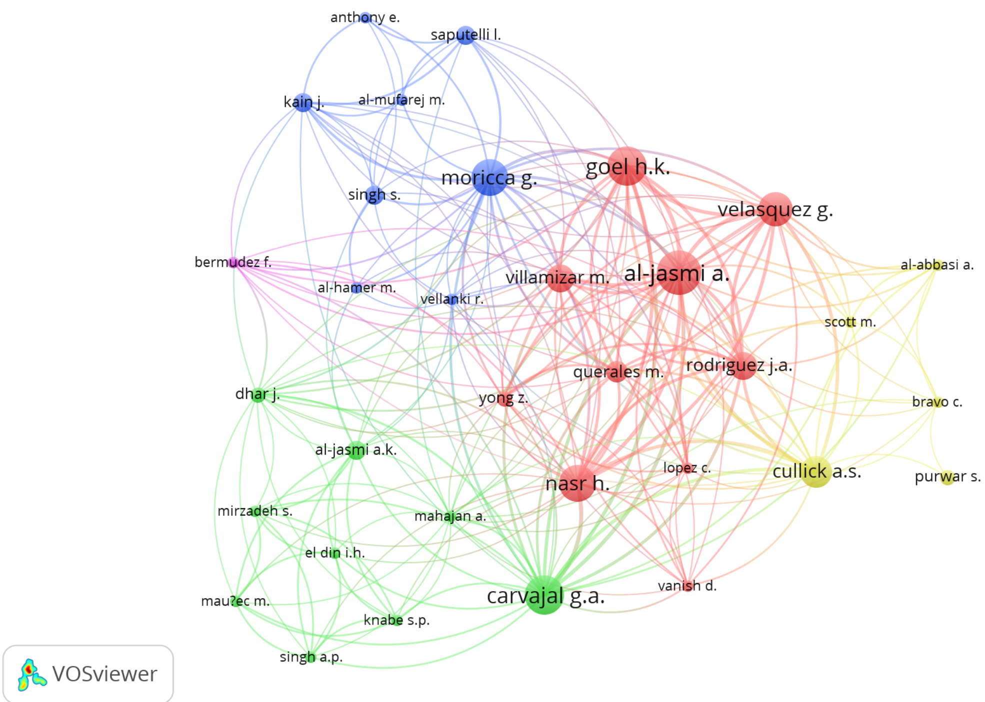
Access to the full text of journal articles and conference papers from the O&G sector is very limited as most are published on OnePetro, to which Cambridge does not currently subscribe. A negligible number of academic papers in this area are Open Access. Therefore, the literature consulted is primarily from market reports that are available freely online or sourced from business databases. The source of much of this information is from the sector itself, which may not be the most circumspect about the challenges it has faced. Some advice can be pieced together from this information, though it should be taken with the caveat that it is based on an incomplete picture of existing research. For more information about the methods used, see APPENDIX: BIBLIOMETRICS IN DETAIL.

In the top 20 most cited papers of all time, most come from the Society of Petroleum Engineers (SPE) Digital Energy Conference from 2013. Indeed, the majority of the literature comes from conferences and specifically SPE conferences, and author affiliations are more often O&G companies than academic institutions. The documents identified here have relatively small lists of references are cited relatively few times. This is unsurprising, given how many of the authors are affiliated with O&G

companies rather than universities. Co-authorship and co-citation networks show existing collaborations, but paint a picture of a relatively insular discipline.

Those articles that were inspected more closely tended to be either a top level view or else highly specific. Many explore technical details such as predictive modelling methods, software for visualisation and data storage solutions, relatively few of which seemed to be at the evaluation stage after implementation in situ. Others seemed to have been written simply to define concepts like "big data" and how they might apply in the O&G sector. A number of case studies were identified, but lack of access to the full text meant that it was difficult to tell how useful these would be to the aims of CDBB.

Co-authorships

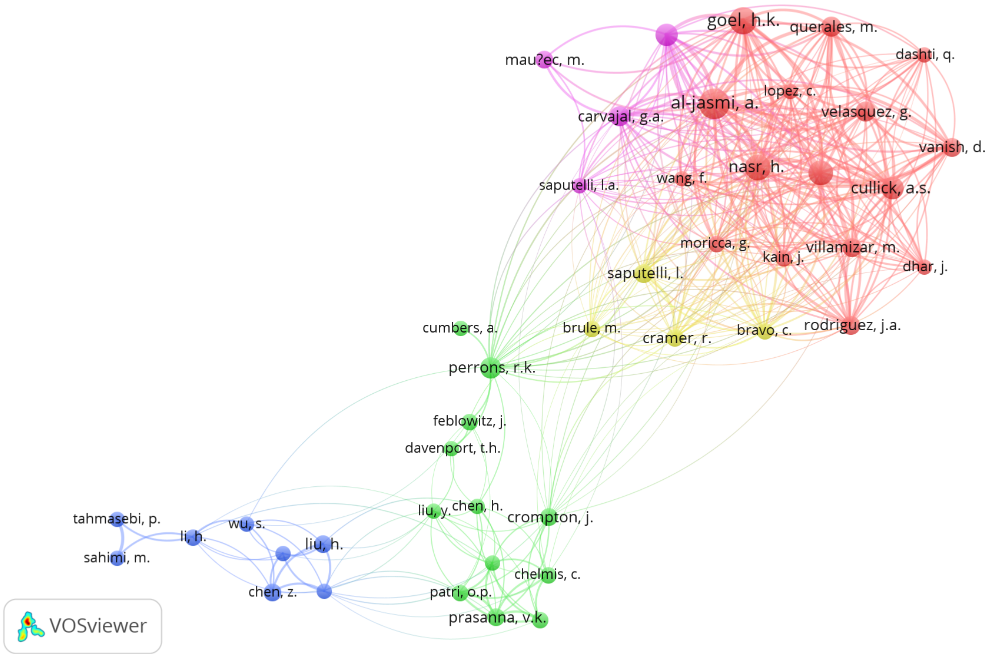


The image above shows the main network of co-authors in the identified literature. This network of authors who frequently collaborate with each other is chiefly based at Kuwait Oil Company and Halliburton. Of these, al-Jasmi from Kuwait Oil Company is a central figure. As with the larger body of literature, the majority of al-Jasmi's papers have been published by the Society of Petroleum Engineers, primarily the 2013 Digital Energy conference. This cohort seems to have published several papers together in 2013, and each of them has a spike in papers and citations in that year.

Beyond this network, the other significant clusters centre on the University of Southern California; Hitachi Research and Development group; collaboration between researchers at Beijing Institute of Technology and the University of Calgary's Department of Chemical and Petroleum Engineering; and collaboration between University of Oslo, Oxford and the Free University of Bozen-Bolzano researchers. These are evidently key research centres for smart oilfields and related technologies.

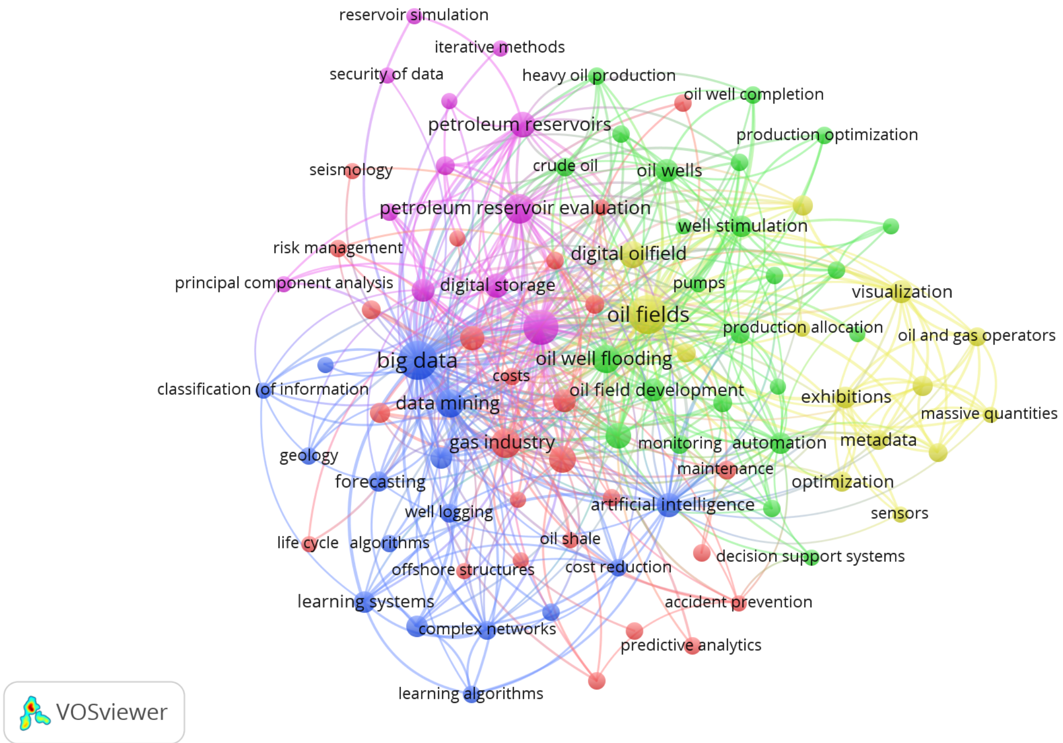
There were a large number of authors without a significant network of co-authors in this body of literature. These may link out to computer science or data science, management or economics fields and so their co-author networks are not represented by this body of literature. However, given how many of the authors have business affiliations rather than academic affiliations, they may not collaborate with other academic fields.

Co-citation



The co-citation network shows that the clusters of co-authors are not as isolated as they appear when simply considering direct collaboration. The cluster in the centre linking the Kuwait Oil Company and Hitachi author clusters is Crompton from Chevron, Perrons from Shell, Feblowitz from Advanced Market Research and Chelmis, formerly of the University of Southern California. Perrons works in the area of transition management and learning from digitalisation in other sectors. Given his prior association with the University of Cambridge, he has the potential to be a useful collaborator.

Keywords



The network above shows the most common keywords used to index the identified literature and which words are used together most frequently. As *big data* was one of the search criteria it is unsurprising that it dominates the figure. A number of the keywords focus on outcomes expected from a smart oilfield; *visualisation*, *accident prevention*, *production optimization*, *forecasting*, *maintenance*, *real-time monitoring*, *cost reduction*. Others focus on the technology used to accomplish these; *data mining*, *SCADA systems*, *cloud computing*, *learning algorithms*, *complex networks*, *predictive analytics*. Paying attention to the terms coming up in other sectors may help start to refine what outcomes and technologies might characterise the Integrate and Operate space of BIM and digital built environments.

Further research

Aerospace and Product Lifecycle Management will be explored in similar ways in upcoming reports, followed by a synthesis of the challenges and solutions from sectors who are further along the digitalisation curve than AEC. This final report will look at overlapping literature between the sectors using co-citation networks and will explore emerging trends by looking at the changes in keywords over time. It is hoped that this will provide an overview of existing collaborative networks as well as an outline of what outcomes and technologies could define “Level 3” or the Integrate and Operate space toward which CDBB is working.

Bibliography

- Buchan, K. (2017, October). Integration Of Wireless Systems To The Digital Oil Field. *E & P; Houston*.
- Cyber security. (n.d.). [Wiki]. Retrieved 22 February 2018, from http://petrowiki.org/Cyber_security
- Deloitte Insights. (2017). *An integrated approach to combat cyber risk: securing industrial opeartions in oil and gas*. Retrieved from https://www2.deloitte.com/us/en/pages/energy-and-resources/articles/integrated-approach-combat-cyber-risk-energy.html?nc=1
- Deloitte Insights. (2018). Protecting the connected barrels. Retrieved 22 February 2018, from https://www2.deloitte.com/insights/us/en/industry/oil-and-gas/cybersecurity-in-oil-and-gas-upstream-sector.html
- Ershaghi, I., & Omoregie, Z. S. (2005). Continuing-Education Needs for the Digital Oil Fields of the Future. Presented at the SPE Annual Technical Conference and Exhibition, Society of Petroleum Engineers. https://doi.org/10.2118/97288-MS
- Lo, C. (2014, November 26). Crewing up for the digital oil field. Retrieved 22 February 2018, from https://www.offshore-technology.com/features/featurecrewing-up-for-the-digital-oil-field-4447343/
- Matson, J. R., & Krome, J. D. (2007). The Intelligent Oilfield - Point Of View. Presented at the Offshore Mediterranean Conference and Exhibition, Offshore Mediterranean Conference. Retrieved from https://www.onepetro.org/conference-paper/OMC-2007-171
- Mayer, W., Stumptner, M., Grossmann, G., & Jordan, A. (2013). *Semantic Interoperability in the Oil and Gas Industry: A Challenging Testbed for Semantic Technologies* (Semantics for Big Data AAAI Technical Report No. FS-13-04). Retrieved from https://www.aaai.org/ocs/index.php/FSS/FSS13/paper/viewFile/7602/7550
- Mittal, A., Slaughter, A., & Bansal, V. (2017). From bytes to barrels. Retrieved 23 February 2018, from https://www2.deloitte.com/insights/us/en/industry/oil-and-gas/digital-transformation-upstream-oil-and-gas.html
- Open Industrial Interoperability Ecosystem (OIIE) | MIMOSA. (n.d.). Retrieved 26 February 2018, from http://www.mimosa.org/open-industrial-interoperability-ecosystem-oiie
- Perrons, R. K., & Hems, A. (2013). Cloud computing in the upstream oil & gas industry: A proposed way forward. *Energy Policy*, *56*, 732–737. https://doi.org/10.1016/j.enpol.2013.01.016
- Perrons, R. K., & Jensen, J. W. (2015). Data as an asset: What the oil and gas sector can learn from other industries about "Big Data". *Energy Policy*, *81*, 117–121. https://doi.org/10.1016/j.enpol.2015.02.020
- Perrons, R. K., & Richards, M. G. (2013). Applying maintenance strategies from the space and satellite sector to the upstream oil and gas industry: A research agenda. *Energy Policy*, *61*, 60–64. https://doi.org/10.1016/j.enpol.2013.05.081
- Rueb, D., & Alaybeyi, S. B. (2018). Market Guide for IoT Service Providers. Retrieved 22 February 2018, from https://www.gartner.com/document/3842378?ref=ddrec
- Technavio. (2015). *Global Oilfield Communications Market 2015-2019*.
- Technavio. (2016a). *Global Automation Solutions Market in the Oil and Gas Industry 2016-2020*.
- Technavio. (2016b). *Global Drilling Data Management Systems Market 2016-2020*.
- Technavio. (2016c). *Global SCADA Market in Oil and Gas Industry 2016-2020*.
- Technavio. (2017a). *Global Digital Oilfield Market 2017-2021*.
- Technavio. (2017b). *Global Oil and Gas Insturmentation Market 2017-2020*.

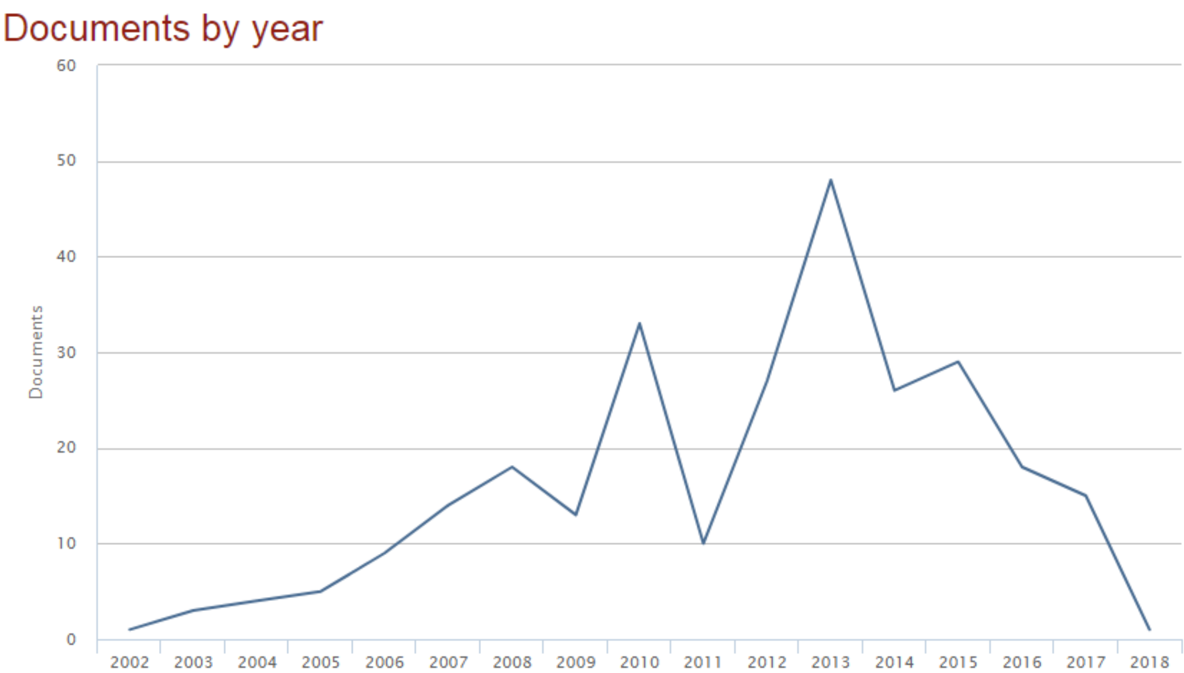
- Urquhart, L., & McAuley, D. (2017). *Cybersecurity Implications of the Industrial Internet of Things* (SSRN Scholarly Paper No. ID 2971991). Rochester, NY: Social Science Research Network. Retrieved from https://papers.ssrn.com/abstract=2971991
- Vicki Harris - Manager, Cloud Center of Excellence and Programs, Chevron Corporation. (2017). *Boardroom Insiders Profiles; San Francisco*. Retrieved from https://search.proquest.com/docview/1984354716/abstract/98EAE04F0EAD4770PQ/8
- World Economic Forum, & Accenture. (2017). *Digitalization: A New Era for Oil and Gas*. Retrieved from http://reports.weforum.org/digital-transformation/wp-content/blogs.dir/94/mp/files/pages/files/dti-oil-and-gas-industry-white-paper.pdf

Appendix: Bibliometrics in Detail

This section outlines the method chosen for identifying the relevant literature, as well as showing bibliometrics for two example searches, as evidence of the characterisation of the literature provided in the BIBLIOMETRICS section of the report. Since the desired outcome of this section of the project was to identify challenges faced by offshore O&G during the digitisation process and potential solutions, the logical starting point was grey literature, which would point to industry-focused solutions. As predicted from such a competitive IP environment, there are relatively few specifics published openly. The first useful resources encountered were market reports. These provided most of the information in the report and helped identify terminology that helped shape searches of the scholarly databases.

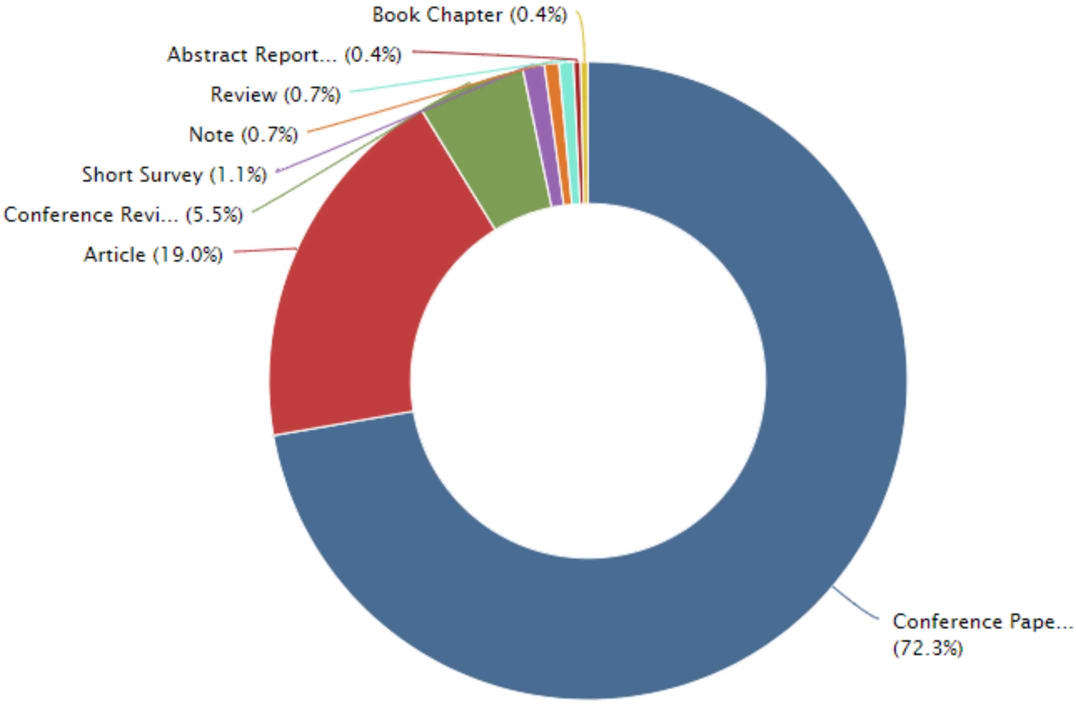
The next step planned was to attempt to identify academic authors who discuss problems found in the grey literature. However, the lack of access to full text of articles and conference papers prevented a comparison of these texts.

Scopus 27/02/2018: (TITLE-ABS-KEY ("smart oilfield") OR ("digital oilfield")) = 274

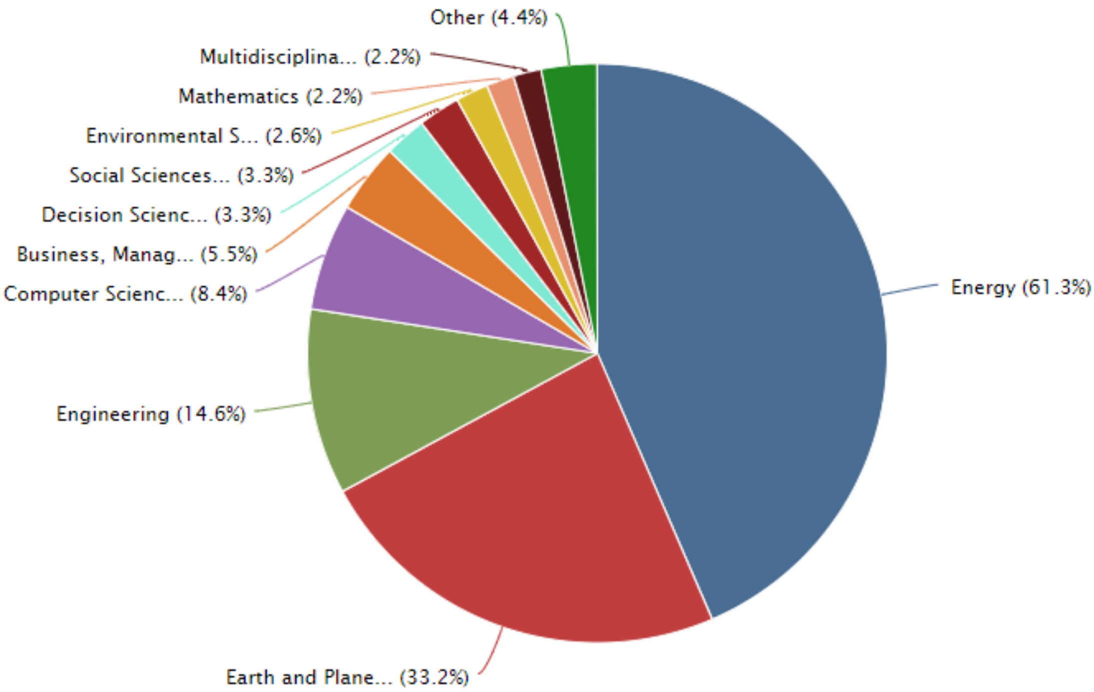


Documents by year (2002-2018): Peak in 2013 with 48 documents

Documents by type



Documents by subject area



Top Sources:

1. Proceedings SPE Annual Technical Conference And Exhibition (25)
2. Hart S E And P (10)
3. Advanced Materials Research (6)
4. Offshore Engineer (6)
5. Journal Of Xi An Shiyou University Natural Sciences Edition (6)
6. Applied Mechanics And Materials (4)
7. Journal Of Petroleum Technology (4)
8. Offshore (4)
9. World Oil (4)
10. Proceedings Of The Annual Offshore Technology Conference (3)
11. SPE Economics And Management (3)

Top Authors:

1. Al-Jasmi, A. (19)
2. Carvajal, G.A. (14)
3. Goel, H.K. (13)
4. Prasanna, V.K. (13)
5. Nasr, H. (11)
6. Cullick, A.S. (10)
7. Moricca, G. (10)
8. Velasquez, G. (10)
9. Rodriguez, J.A. (8)
10. Chelmis, C. (7)
11. Villamizar, M. (7)

Top Affiliations:

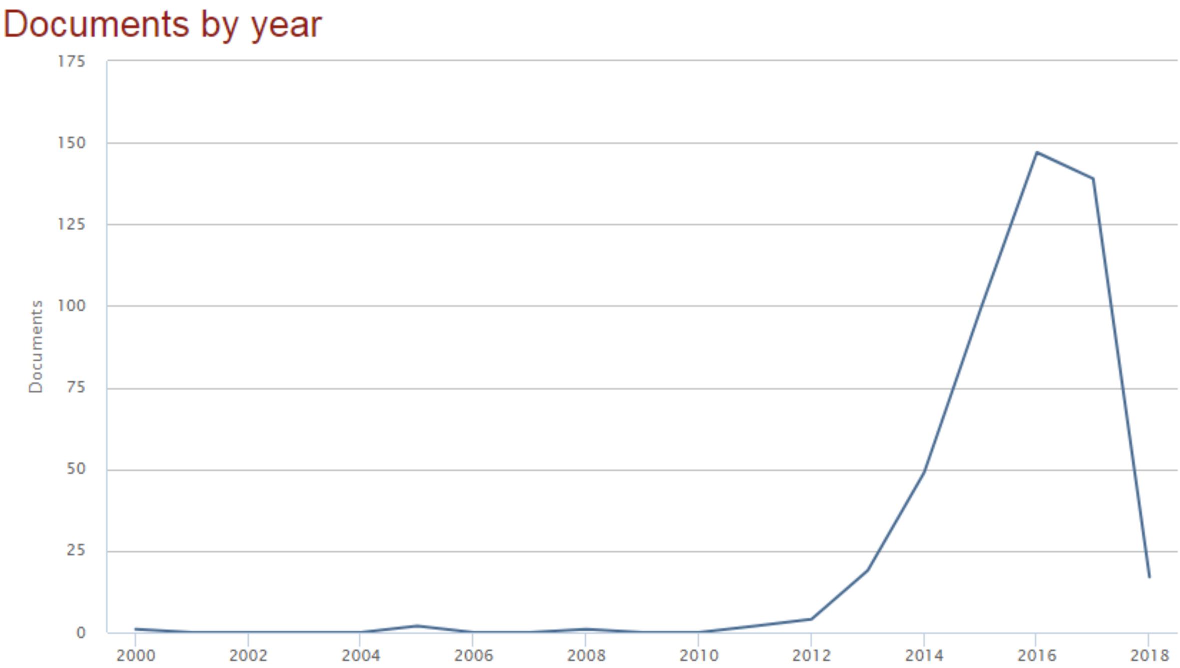
1. Halliburton (35)
2. Kuwait Oil Company (26)
3. Chevron Corporation (21)
4. University of Southern California (19)
5. Society of Petroleum Engineers International (11)
6. BP (8)
7. Berry Petroleum Company (7)
8. Yangtze University (6)
9. SAIC (4)
10. Xi'an Shiyou University (4)

Top Countries:

1. United States (140)
2. China (39)
3. Kuwait (27)

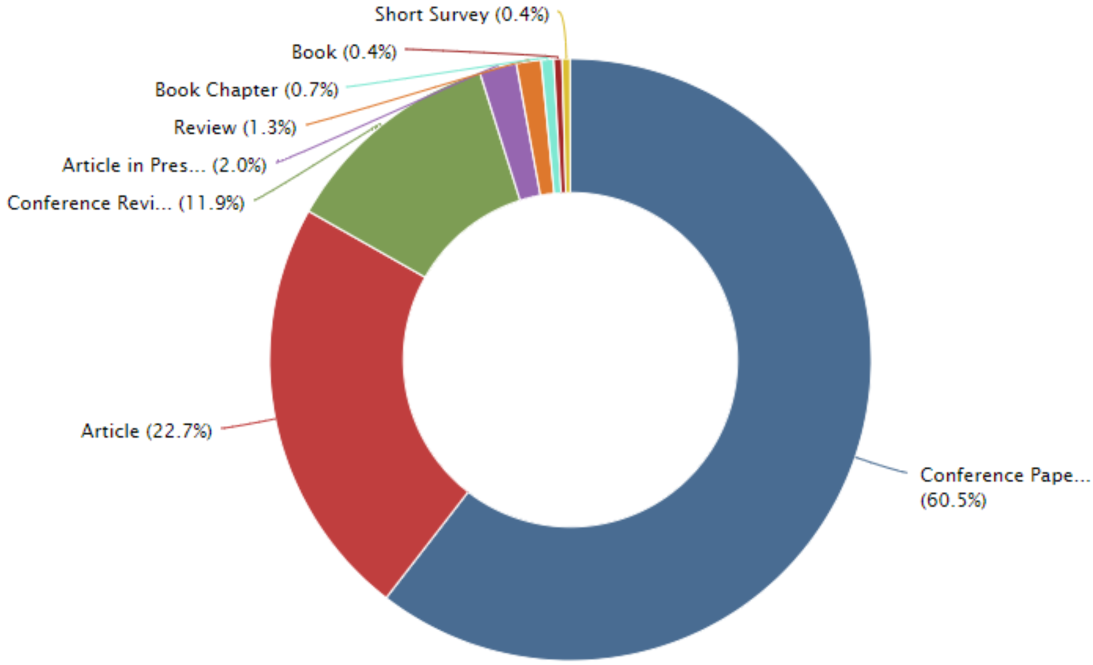
4. United Kingdom (13)
5. Brazil (5)
6. Norway (5)
7. Russian Federation (5)
8. Australia (4)

Scopus 27/02/18: (TITLE-ABS-KEY (oil OR gas* OR petrol*) AND TITLE-ABS-KEY ("big data" OR "cognitive computing")) = 576

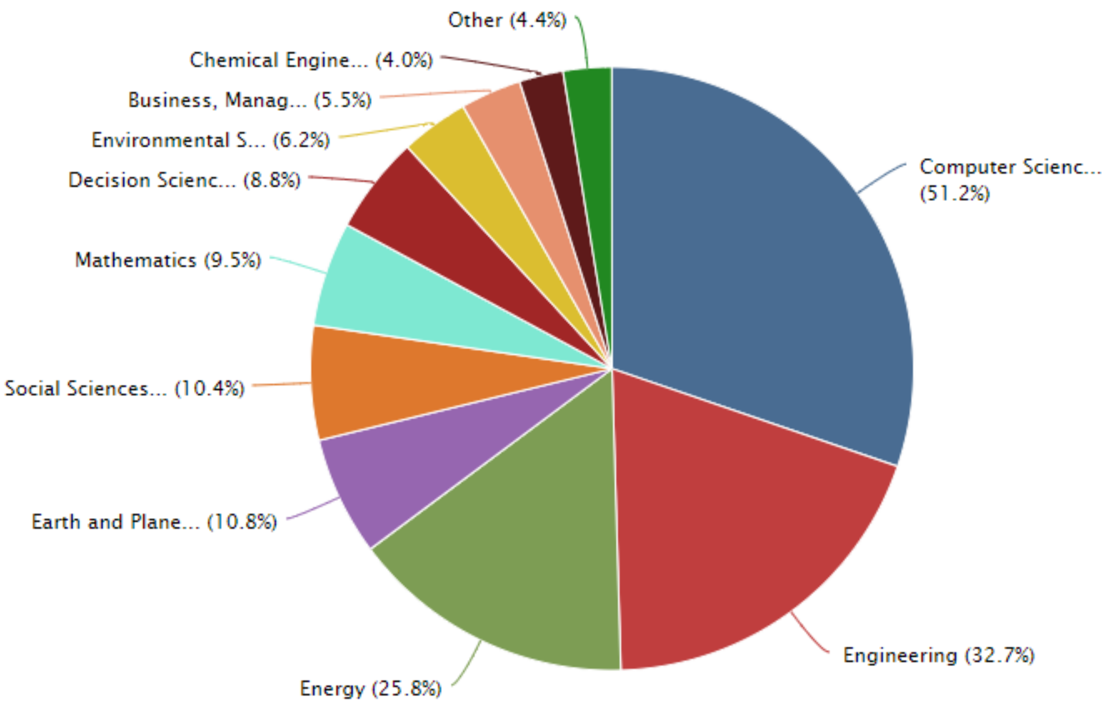


Limited by: (EXCLUDE (SUBJAREA , "MEDI") OR EXCLUDE (SUBJAREA , "PHYS") OR EXCLUDE (SUBJAREA , "BIOC") OR EXCLUDE (SUBJAREA , "CHEM") OR EXCLUDE (SUBJAREA , "ARTS") OR EXCLUDE (SUBJAREA , "HEAL") OR EXCLUDE (SUBJAREA , "IMMU") OR EXCLUDE (SUBJAREA , "NEUR") OR EXCLUDE (SUBJAREA , "AGRI") OR EXCLUDE (SUBJAREA , "NURS") OR EXCLUDE (SUBJAREA , "PHAR") OR EXCLUDE (SUBJAREA , "PSYC")) and years 2013-2017 = 453

Documents by type



Documents by subject area



Top Sources:

1. Proceedings SPE Annual Technical Conference And Exhibition (17)
2. Lecture Notes In Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics (15)
3. Procedia Computer Science (11)
4. Advances In Intelligent Systems And Computing (6)
5. CEUR Workshop Proceedings (6)
6. Journal Of Cleaner Production (6)
7. IFIP Advances In Information And Communication Technology (5)
8. Proceedings Of The Annual Offshore Technology Conference (5)

Top Authors:

1. Vennelakanti, R. (5)
2. Chen, Z. (4)
3. Liu, H. (4)
4. Nimmagadda, S.L. (4)
5. Sahu, A. (4)
6. Wang, K. (4)
7. Zhang, Q. (4)

Top Affiliations:

1. Chinese Academy of Sciences (12)
2. China University of Petroleum – Beijing (7)
3. Research Institute of Petroleum Exploration and Development (7)
4. University of Texas at Austin (6)
5. Halliburton (6)
6. International Business Machines (5)
7. Tsinghua University (5)
8. Hitachi America, Ltd. (5)

Top Countries:

1. United States (123)
2. China (109)
3. United Kingdom (18)
4. Germany (16)
5. Australia (15)
6. Norway (12)
7. India (11)
8. Canada (10)
9. Russian Federation (10)
10. France (8)
11. South Korea (8)

Scopus 27/02/18: (TITLE-ABS-KEY (upstream OR extraction) AND TITLE-ABS-KEY (oil OR gas* OR petrol*) AND TITLE-ABS-KEY ("information management")) AND (EXCLUDE (SUBJAREA , "PHYS") OR EXCLUDE (SUBJAREA , "SOCI") OR EXCLUDE (SUBJAREA , "AGRI") OR EXCLUDE (SUBJAREA , "BIOC") OR EXCLUDE (SUBJAREA , "CHEM") OR EXCLUDE (SUBJAREA , "HEAL") OR EXCLUDE (SUBJAREA , "MEDI") OR EXCLUDE (SUBJAREA , "ARTS") OR EXCLUDE (SUBJAREA , "ECON")) = 102

This search generated quite a few false positives, but a key author was identified from this search dealing with the transition to cloud-based big data in O&G, Perrons from Queensland University of Technology, Brisbane, Australia. Most importantly, he tends to publish in journals on the periphery of the O&G sector and so more of his articles were accessible. He had a former affiliation with Shell and with Cambridge through the Institute of Manufacturing, and as he is working in the research space of transition and learning from other sectors, he may be a useful collaborator.

Profile of R.K. Perrons

Top co-authors:

1. Platts, Ken W. (5)
2. Richards, Matthew G. (3)
3. Hughes, Mathew (2)
4. Jensen, Jesse W. (2)
5. Tan, Kimhua (2)
6. Hems, Adam (2)

Top Sources:

1. Journal Of Petroleum Technology (5)
2. Energy Policy (3)
3. Energy Exploration And Exploitation (2)
4. Marine Pollution Bulletin (2)
5. Proceedings SPE Annual Technical Conference And Exhibition (2)
6. SPE Intelligent Energy Conference And Exhibition 2010 (2)

By subject area:

1. Energy (17)
2. Business, Management and Accounting (14)
3. Environmental Science (6)
4. Engineering (5)
5. Earth and Planetary Sciences (4)
6. Computer Science (3)
7. Decision Sciences (3)
8. Agricultural and Biological Sciences (2)
9. Economics, Econometrics and Finance (2)
10. Social Sciences (2)

Searches used to create VosViewer network

The following searches were run on Scopus to create a spreadsheet that could be put through VosViewer. The results were de-duplicated automatically and then checked by hand for any obvious false positives (judged by title or source) and remaining duplicates. The remaining titles formed the basis of the VosViewer analysis in the BIBLIOMETRICS section of the report.

- 16/02/18: (TITLE-ABS-KEY (offshore AND (oil OR gas) AND industry) AND TITLE-ABS-KEY (technology W/3 deployment OR insertion) = 27
- 16/02/18: TITLE-ABS-KEY (offshore AND (oil OR gas) AND industry) AND TITLE-ABS-KEY (monitor* OR sensor AND data) AND TITLE-ABS-KEY (network)) AND (EXCLUDE (SUBJAREA , "CENG") OR EXCLUDE (SUBJAREA , "BIOC") OR EXCLUDE (SUBJAREA , "CHEM") OR EXCLUDE (SUBJAREA , "HEAL") OR EXCLUDE (SUBJAREA , "IMMU") OR EXCLUDE (SUBJAREA , "MEDI") OR EXCLUDE (SUBJAREA , "NEUR") OR EXCLUDE (SUBJAREA , "PHAR") = 54
- 16/02/18: TITLE-ABS-KEY ("digital oil*field") AND TITLE-ABS-KEY (integrat* AND data)) AND (LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) = 40
- 16/02/18: TITLE-ABS-KEY ("digital oil*field") AND implement* = 138
- 16/02/18: TITLE-ABS-KEY ("digital oil*field") AND adopt* = 41
- 27/02/2018: TITLE-ABS-KEY ("smart oilfield") OR TITLE-ABS-KEY ("digital oilfield") = 274
- 27/02/2018: TITLE-ABS-KEY (oil OR gas* OR petrol*) AND TITLE-ABS-KEY ("big data" OR "cognitive computing") = 576
- 27/02/18: TITLE-ABS-KEY (upstream OR extraction) AND TITLE-ABS-KEY (oil OR gas* OR petrol*) AND TITLE-ABS-KEY ("information management")) AND (EXCLUDE (SUBJAREA , "PHYS") OR EXCLUDE (SUBJAREA , "SOCI") OR EXCLUDE (SUBJAREA , "AGRI") OR EXCLUDE (SUBJAREA , "BIOC") OR EXCLUDE (SUBJAREA , "CHEM") OR EXCLUDE (SUBJAREA , "HEAL") OR EXCLUDE (SUBJAREA , "MEDI") OR EXCLUDE (SUBJAREA , "ARTS") OR EXCLUDE (SUBJAREA , "ECON") = 102

Other Databases

A number of other databases were searched to determine how relevant their coverage was to the topic:

- **Web of Science:** Very low citation rate and low number of articles relative to Scopus. This indicates that the coverage of the O&G literature on this database is poor.
- **Proquest:** Some trade publications and reports.
- **Google Scholar:** Most results were from OnePetro, so not accessible.
- **Google:** A number of open access market reports and write ups that contributed to the report.
- **Technavio:** Market reports focused on technology, so a number of relevant resources.