Big Data: a big opportunity for the petroleum and petrochemical industry*

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Abstract

The Petroleum and Petrochemical (P&P) industry is home to the most traded commodity in the world, i.e. oil. Recently, this industry has been struggling to make ends meet with top lines being affected by falling oil prices and bottom lines being squeezed further via increasing operational costs. It is against this backdrop that this paper seeks to identify and summarise the positive influence that the adoption of Big Data can have on the P&P industry. Exhaustive research is carried out on the industry's engagement and adoption of Big Data in upstream, midstream and downstream operations to concisely summarise the varied applications and the potential benefits. Our research indicates that the upstream sector is actively engaging with Big Data to achieve efficiency gains while the midstream and downstream sectors are lagging behind. Overall, it is evident that the P&P industry can find solutions to its aching financial and productivity issues by embracing of Big Data.

1. Introduction

The emergence of Big Data has revolutionised every industry around the globe and, the petroleum and petrochemical (P&P) industry is no exception. In fact, innovation in oil and gas is increasingly being used to refer to advances in Big Data, predictive analytics, data science and machine learning (Cowles, 2015) in an industry where the amount of data generated is beginning to explode, with sensors collecting real-time information at a rate of 4 ms (Boman, 2015). The P&P industry, which incorporates upstream, midstream and downstream processes, is recognised as one of the first sectors to identify and

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understand the countless possibilities which Big Data could bring to the private sector (Cowles, 2015; Dyson, 2016).

This is likely a result of the industry requiring large amounts of data to determine new drill sites and ensure sustainable production, among other tasks. Moreover, reports indicate that a modern unconventional drilling operation produces up to 1 MB of data per foot drilled, and it is no secret that such information can be exploited to optimise drill bit location, improve subterranean mapping, enhance efficiencies related to production and transportation, and predict the location of the next promising formation, if analysed appropriately via Big Data analytics (Martin, 2015). Evidence in (Feblowitz, 2012; Cowles, 2015; Microsoft, 2015a) indicate that the data-driven P&P industry and its upstream sector is experiencing exponential growth in data volumes.

Big Data is here to stay, with the market for Big Data solutions and services is expected to reach $5.41 billion by 2020 (Technavio, 2015). While the concept of Big Data is relatively new to certain industries, it is not new to the P&P industry as Big Data's inherent ability to uncover invisible trends and patterns has long been exploited by this industry (Dyson, 2016). However, even though P&P companies are investing increasingly in information technology and analytics (Martin, 2015), as noted in (Dyson, 2016), in comparison to the P&P industry's interest in innovation-orientated sectors like the tech sector, the interest shown for maximising the opportunities put forward by Big Data has been slow moving.

Moreover, according to McKinsey research, the P&P industry only generates value from a mere 1 per cent of all the data it creates (DiChristopher, 2015; McKinsey Global Institute, 2015). Given that the world is running low on easily accessed Oil and Gas (O&G), the P&P industry utilises Big Data analytics to boost production via exploiting sensors, high-speed communications and data-mining techniques to monitor and fine-tune remote drilling operations (Leber, 2012). Therefore, it is prudent that we consider the current opportunities and applications of Big Data in the O&G industry to motivate, promote and showcase its importance, and related productivity and efficiency gains to the wider P&P industry. Furthermore, this work seeks to address the lack of relevant studies in the literature on the uptake and impact of Big Data in the P&P industry, as was also noted in (Vega-Gorgojo *et al.*, 2016). After all, Big Data is the oil of the new economy (Baaziz and Quoniam, 2013) and the P&P industry is one where small improvements in efficiency and productivity can result in significant economic gains (Cowles, 2015).

In the context of the P&P industry, Big Data refers to large quantities of data coupled with increasing diversity and rate and is enabling O&G companies to improve efficiency and reduce costs—a benefit that is being passed on to consumers (Blair, 2015). **Figure** 1 summarises the 5V's of Big Data and any Big Data system is expected to deliver one or

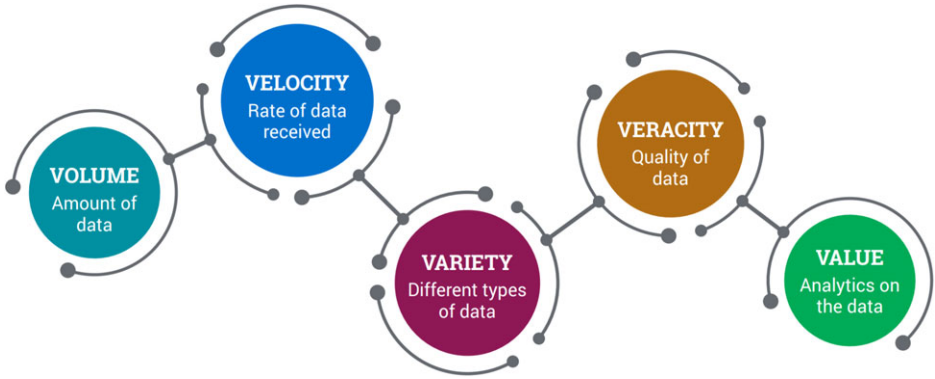

Figure 1 The 5V's of Big Data (Quorum, 2016). [Colour figure can be viewed at wileyonlinelibrary.com]

more of these 5V's (Quorum, 2016). On the other hand, Big Data analytics is defined in (Feblowitz *et al.*, 2013) as 'technologies and architectures designed to economically extract value from very large volumes of a wide variety of data (structured and unstructured) by enabling high-velocity capture, discovery, and/or analysis.' Others argue that Big Data is no longer about the amount or mass of data, but instead is increasingly concerned with the diversity of data (Fierstien, 2016). Meanwhile, another term which is emerging is 'Dark Data' which refers to 'the information assets organisations collect, process and store during regular business activities, but generally fail to use for other purposes' (Bagherian, 2015). In brief, it refers to data that has the potential to provide useful insights but has not been mined and analysed yet (Bagherian, 2015).

Historically, within the P&P industry, Big Data was most commonly exploited for seismic interpretation software, to discover O&G reserves which would otherwise have been difficult to locate (Dyson, 2016). However, with the ever-increasing volume of data, traditional analysis tools and storage technologies would now fail in capturing, managing and uncovering hidden information (Baaziz and Quoniam, 2014; Soo and Perez, 2014), and therefore P&P companies should give more attention and focus to Big Data and related technologies. Currently, most P&P companies fail to exploit the true potential of Big Data owing to a lack of collaboration, limited access to industry leading Big Data-related computer programs and software processing tools, lack of data integration and lack of human capital (Lloyd's Register, 2015) with the knowledge and skills to apply Big Data techniques (Dyson, 2016). As noted in (Ismail, 2017), there is a growing demand for graduates who possess sufficient knowledge of petroleum fundamentals, Big Data analytic skills and the ability to leverage artificial intelligence to deliver cost-effective insights. These concerns are in addition to the various other

challenges that must be overcome in the pursuit of productively exploiting Big Data, and those interested in a discussion are referred to (Hassani and Silva, 2015).

The successful exploitation of Big Data requires the combined efforts of businesses as a whole, its management and IT departments so that a mandatory technology infrastructure could be developed (Soo and Perez, 2014). One example of such infrastructure which can provide a reliable foundation is the Microsoft Upstream Reference Architecture (MURA) (Microsoft, 2015b) which is presented via **Fig.** 2. MURA captures the key trends that drive the upstream P&P industry including the human capital aspect and exceeds in mapping business trends (Microsoft, 2015b).

The effective exploitation of Big Data can undoubtedly help P&P companies gain new insights, enhance business value, improve bottom lines and attain a true competitive advantage (Microsoft, 2015a). Moreover, given that the P&P industry is prone to high-risk, Big Data analytics can help the industry to automate high-cost, dangerous or error-prone tasks, which will result in improved safety via minimised risks to human lives (Martinotti *et al.*, 2014). The major uses of Big Data within the P&P sector have been noted as boosting production rates, reducing non-productive time, predicting equipment failure, decision support for project planning and trading, de-risking exploration and regulatory compliance and early event detection (Jacques, 2016).

The P&P industry can be broken down into three categories known as upstream, midstream and downstream. Upstream activities include exploration, discovery, drilling and production while midstream activities include transportation, wholesale markets, and manufacturing and crude refinement, whereas downstream activities include the delivery of refined products to the consumer (Cowles, 2015). In what follows, we look at the

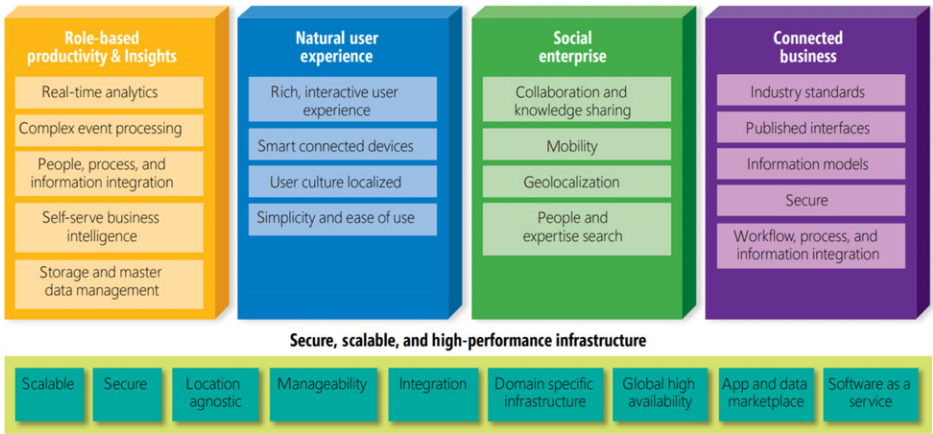

Figure 2 The guiding principles of MURA (Soo and Perez, 2014). [Colour figure can be viewed at wileyonlinelibrary.com]

impact of Big Data in the P&P industry by focussing on upstream, midstream and downstream operations. Section 2 is dedicated to upstream, Section 3 is dedicated to midstream, Section 4 to downstream while Section 5 looks at what the future is expected to offer the P&P industry in relation to Big Data. The paper concludes in Section 6.

2. Big Data in upstream

The upstream operations within the P&P industry generates vast amounts of data which has until recently been too enormous to process effectively (Ward, 2016). The P&P industry is faced with significant challenges from the upstream industry's operational environment, and their top and bottom lines are taking a considerable hit (Mathew, 2016). At present, only 3–5$ of P&P equipment is connected, with most data being used for control and detection of issues as opposed to optimising asset performance (Mathew, 2016). In line with this, there is evidence of Big Data driving fault detection in catalytic cracking units (Yuan *et al.*, 2017). Estimates indicate that operational efficiency could be boosted by 20 per cent if the industry can analyse and understand all the data it produces (Ward, 2016). As noted in (Mathew, 2016), digital technologies can transform upstream operations and create additional profits from existing capacity, thereby making the industry more productive and more agile. Research by Bain and Company indicates that Big Data analytics can improve oil field and plant performance by 6–8 per cent (Bertocco and Padmanabhan, 2014). In what follows, we focus more closely on upstream operations in relation to its exploitation of Big Data.

2.1. Exploration and discovery

There is evidence which shows the use of Big Data for exploration in the P&P industry. According to (Barney, 2015), energy exploration is one of the most significant Big Data applications within the P&P industry. Big Data is already used for smartening the drilling platforms and pipeline infrastructure to enable anticipation of issues and prevention of failures (Seshadri, 2013). Shell Gas, exploits Big Data to reduce the costs of oil extraction by partnering with Hewlett-Packard and Amazon Web Services. Together, they gather and transfer millions of readings via fibre-optic cables and use this data to obtain a more accurate vision of what lies underneath (Lucero, 2015; Marr, 2015; Natkar, 2016). Moreover, as noted in (Bertocco and Padmanabhan, 2014; Crooks, 2018), the ability to transmit micro-seismic 3D imaging over fibre-optic cables can help improve new well delivery performance.

Where environmental regulations restrict new surveys, scientists are now relying on pattern-based analysis of historical Big Data (Technavio, 2015). Shell Gas also uses Big Data from sensors placed within its exploration equipment to minimise equipment

downtime and reduce overhead costs (Lucero, 2015). Another example is the complementing of seismic data with novel sensors by companies like Glori Energy and Environmental BioTechnologies while companies like Silixa and HiFi Engineering are introducing smart pumps (Jacques, 2016).

Big Data also has the potential to help P&P companies discover hydrocarbon deposits which requires a huge amount of materials, manpower and logistics. In (Feblowitz *et al.*, 2013) it is stated that Big Data analytics in the form of pattern recognition, when applied to a more comprehensive set of seismic data, can help identify productive seismic trace signatures which were previously overlooked. This fact is noted again in (Soo and Perez, 2014) where the authors note that Big Data in combination with advanced analytics can help perform identity traces. As (Baaziz and Quoniam, 2013) asserts, the analysis of 3D seismic data in terms of its geometry and comparing with neighbouring wells requires the processing of large quantities of data which enable a more accurate outlook for detecting hydrocarbon deposits. Magnetic resonance imaging (MRI) technology is used to identify rock and fluid properties and produces Big Data that can be stored and analysed (Blair, 2015). Wide azimuth towed streamer acquisition (WATS) technology is being used by Chevron and British Petroleum to locate new oil fields by creating high-resolution topographic maps under the earth and beneath salt canopies (Cowles, 2015).

The large amounts of data collected during exploration via seismic wave monitors can help with new oil deposit discoveries while weather, soil and equipment data can be used to predict the success of drilling operations and thereby have a direct impact on cost and revenue (Natkar, 2016). Another innovative technology used for subsurface investigation and exploration is ground penetrating radar (GPR) which allows the gathering, analysis and processing of Big Data and reduces extraction costs (OilVoice, 2016). Overall, within the context of exploration, Big Data analytics can aid in reducing lag time and technical risks and improve drilling parameters (Technavio, 2015).

2.2. Drilling

Big Data presents opportunities for O&G companies to get more oil or gas out of new or existing wells, while mitigating environmental risks (Rijmenam, 2015). For example, the collection and analysis of real-time data via Big Data analytics enables early identification of drilling anomalies so that decisions can be made in time to shut down operations to prevent any large environmental risks (Rijmenam, 2015). The regulators are also forcing the P&P industry to adopt Big Data with regulations from the Bureau of Safety and Environmental Enforcement (BSEE) now requiring offshore drillers to monitor safety critical equipment in real-time and archive the data onshore (Smith, 2016).

Given the high costs of drilling a deep water well, which is estimated at over $100 million (Marr, 2015), Big Data has the potential to help P&P companies attain a

successful drilling operation. The environment is constantly changing and therefore it is clear that the analysis of huge amounts of data pertaining to geology and operations can enhance drilling, spacing of wells and well completion (Blair, 2015). Big Data can be exploited to help with drilling and finishing wells, building pipelines and optimising the world of O&G via the storage and analysis of the wealth of information produced by the machines involved in the aforementioned tasks (Blair, 2015). Big Data also helps identify anomalies that would impact drilling and such early detection can save millions in equipment and labour costs (Soo and Perez, 2014). In addition, real-time information from Supervisory Control and Data Acquisition (SCADA) systems can be used to maximise asset performance and optimise production (Soo and Perez, 2014). A recent concept is that of digital oil fields. Digital oil fields have been defined as 'tools and initiatives relying on use of advanced and specialised software along with data analysis techniques to enhance productivity and profitability of energy companies, for the enhancement of operational efficiency, optimisation of production, data integration and automation of machinery and workflow' (Ahmar, 2016). The standards for the digital oil well, digital oil field and data formats have led to gauges and other data devices on equipment to capture all possible data (Blair, 2015).

Another interesting statistic is that 70 per cent of the world's O&G comes from mature wells (Gillette, 2017). Recent advances in Big Data from sensors and advances in analytics have enabled the development of modern Enhanced Oil Recovery (EOR) techniques which makes it possible to enhance the productivity of mature wells, which in the past were believed to have reached its peak (Cowles, 2015). In fact, a 1 per cent increase in production from currently active mature fields can add 2 years to the world's O&G supply (Cowles, 2015). It is reported in (Dyson, 2016) that Big Data techniques can be used for product optimisation too. For example, companies can maximise their return on investment by optimising field depletion planning and de-risk drilling with the aid of Big Data analytics (Dyson, 2016).

As noted in (Dhunay, 2016), technology-based optimisation of oil well performance has been in use for ages, but this was coupled with significant installation costs which made it uneconomical for the mature wells. In contrast, today, the use of lightweight, pump-mounted sensors and secure wireless networks enables comparatively economic data collection which when combined with Big Data analytics software can enable data-driven intelligence to provide increasingly more intelligent and valuable output via the machine's learning capabilities (Dhunay, 2016).

The use of sensors for continuous real-time data collection and monitoring of assets and environmental conditions are popular in the upstream P&P sector (Brul, 2013). Moreover, Big Data from real-time drilling can even help predict the likelihood of drilling success (Feblowitz *et al.*, 2013). Real-time data on weather can be combined with drilling operation data to avoid dangerous conditions for workers and mitigate

environmental risks (Soo and Perez, 2014; Natkar, 2016). Sensors are used on equipment to produce a constant data stream which can signify imminent equipment failure and thereby reduce threats, while Big Data from continuous pipeline monitoring can signal earthquakes and help determine if a shutdown is required (Blair, 2015). Another interesting concept that is being forged by the emergence of Big Data within the P&P industry is the 'industrial internet' which essentially combines machines and extracts intelligent data to enhance the quality of Predictive Asset Maintenance (Dyson, 2016). This is crucial as on average the P&P industry experiences up to 10 per cent downtime which is equivalent to three times the US industrial average (Dodgson, 2016). As (Soo and Perez, 2014) notes, unanticipated equipment failure can be very expensive and Big data analytics can predict failures, alerting crews to repair or replace equipment before the point of failure. One technique used here is survival analysis which predicts the maintenance requirements for field equipment such as compressors through continuous monitoring and modelling, and thereby enables the reduction in downtime to a single day (Harpham, 2016). Predictive maintenance information via Big Data analytics can save P&P companies millions of dollars as servicing a blowout preventer can cost between $10–$16 m, while an offshore well going out of commission can cost about $7 m per day (Dodgson, 2016). Big Data from sensors in equipment when combined with geological data can enable P&P companies to predict failure and understand which equipment works best in which environment (Natkar, 2016).

Drone technology is being used to capture new sources of data via pipeline surveillance, post-hurricane analysis and flare stake inspection in addition to improving safety conditions by removing the need for workers to operate in high-risk environments within the P&P industry (Natkar, 2016). NuPhysicia exploits Big Data to offer telemedicine for workers far from health-care centres (Jacques, 2016). Devon Energy in the United States is also exploiting various forms of Big Data analytics. For example, they use advanced analytics to monitor the speed and location of its vehicle fleet and the need to evacuate workers in areas where hydrogen sulphide is present while text analytics is used to reduce non-productive time (time wasted due to technical or physical difficulties in extraction; Boman, 2015; Kambouris, 2016). In fact, by combining Hadoop, SAS and text data, Devon Energy was able to determine the cause of non-productive time and address this issue, which in turn helped reduce non-productive time by 30 per cent. As noted in (Kambouris, 2016), by reducing high-impact non-productive time, P&P companies can save on average between $500,000 and $1 million per day. The vast amounts of data gathered via 2D, 3D and 4D seismic data imaging can be speedily analysed with multiple parallel processing Big Data analytic platforms which can then help predict the real-time success of drilling operations (Rijmenam, 2015).

2.3. Production

Big Oil is now mining Big Data via tiny sensors attached to production gear in the hope of saving billions of dollars through the avoidance of outages, identification of safety hazards and improved management of supplies (Gopinath and Hampton, 2017). For example, Chevron's Tengiz oilfield in Kazakhstan is expected to include about 1 million sensors (Crooks, 2018). Reports indicate that Big Data analytics has the capability of increasing oil production by 6–8 per cent (Bertocco and Padmanabhan, 2014; Smith, 2016). In fact, Chevron estimates indicate that a fully optimised digital oil field can result in 8 per cent higher production rates and 6 per cent higher overall recovery rates Is this what is meant? (Ahmar, 2016). Schlumberger, the world's largest listed oilfield services group launched a new software called Delfi to maximise output from an entire oilfield via improve coordination of well design and drilling (Crooks, 2018). This new system alone is expected to reduce production costs by 40 per cent within the next 10 years (Crooks, 2018).

Oil recovery from existing wells can also be enhanced by analysing seismic, drilling and production data (Lucero, 2015; Technavio, 2015), and such information can help determine when to make changes in the oil reservoir and when to change oil lifting methods, while cloud computing and Big Data can also help to forecast oil production more accurately (Natkar, 2016). P&P companies exploiting a predictive, data-driven approach to maintenance can experience 36 per cent less unplanned downtime (Yuan *et al.*, 2017) and given that maintenance-related issues can have severe impacts on production, it is opportune to connect to the cloud. For example, an offshore company was able to save $7.5 million in unplanned downtime by replacing a suspect seal on a water injection pump prior to failure (Sponseller, 2015).

3. Big Data in midstream

Given the challenging tasks of transporting variable volumes and grades of products from multiple locations to new end-users and markets, the midstream industries can benefit greatly from the productive application of Big Data analytics for connecting pipelines, sensors, leak detection, alarms and emergency shutdowns (Dixit, 2017). The Internet of Things (IoT) is revolutionising midstream pipeline operations via SCADA-based applications for environmental monitoring and infrastructure management through the monitoring and controlling of operations on pipeline infrastructure (Kivi, 2017).

Midstream companies are exploiting Hadoop to deploy new data-enabled infrastructure and exploiting machine learning algorithms to provide a single view of assets and processes and deliver predictive analytics (Kohlleel, 2015). Big Data is used to streamline the transport and refinement of O&G (Dixit, 2017). LogiLubes SmartOil real-

time oil condition monitoring (OCM) technology helps protect midstream compressors where a drop of just 0.5 per cent in efficiency can cost a natural gas compression operation $180,000 per annum in lost revenue (Gillette, 2017).

4. Big Data in downstream

Big Data's importance for downstream performance is discussed briefly in (Flowers, 2017), but the exploitation of the same specifically for downstream efficiency gains in the P&P industry is rare at present in terms of its documentation within the public domain. The potential for benefit is visible via Shell Gas' use of Big Data with complex algorithms which combine economic indicators and weather patterns to determine demand, set prices and allocate resources more efficiently (Lucero, 2015).

5. The future of Big Data in oil and gas

The survival and future of exploration and production in the P&P industry is expected to be heavily reliant on Big Data and the IoT, given declining oil prices (Dodgson, 2016). According to the 2016 Accenture and Microsoft Digital Energy Trends Survey, 56 per cent of the O&G industry executives believed that exploiting Big Data analytics will be a crucial component of their business strategy over the next 3–5 years (Accenture Consulting, 2016).

However, recent reports indicate that the O&G industry is lagging in terms of its adoption of Big Data (Kivi, 2017) with low oil prices deterring O&G companies from investing in data scientists who can help the industry make the most out of Big Data. The prevalence of this mentality would only affect the industry negatively by compounding existing problems (Dyson, 2016). In contrast, some authors argue that plummeting oil prices are indeed creating a stronger demand for numerous Big Data-led innovations and investments which can deliver increased levels of operational efficiency and automation (Boman, 2015; Dhunay, 2016; Jacques, 2016; Mathew, 2016). Companies like Halliburton are using Big Data techniques to optimise seismic space, drilling space and well planning (Cowles, 2015). Moreover, Big Data in O&G is rapidly becoming a critical competitive advantage and is expected to affect mergers and acquisition activities in the O&G industry via greater focus on IT (Jacques, 2016).

The concept of Cloud Computing is yet another avenue which could benefit from Big Data analytics as it would provide opportunities to perform more complex analyses by exploiting the significantly greater amounts of data in addition to enabling remote working practices which can result in considerable safety improvements in the O&G industry (Dyson, 2016). Cloud computing enable organisations to increase their efficiency and reduce the cost of deploying Big Data solutions (Natkar, 2016). In

addition, authors also note the importance of combining digital oil field initiatives with Big Data analytics to enable better integrated operations and workflows (OE Staff, 2016). Such advances in Big Data are expected to result in lower operational costs, reduced non-productive times (which can in turn reduce costs by approximately 30 per cent; Vennelakanti *et al.*, 2016), less downside risks and less uncertainty (Dyson, 2016).

A company called Intertek is collaborating with the Robert Gordon University in the UK on a research project which aims to help O&G companies make the most of big data, and enable improved asset performance, increased efficiencies, reduced operating costs and safer operations Is this what is meant? (RGU, 2016). The project seeks to develop advanced data science tools which can uncover hidden patterns from the vast amount of data gathered via sensors to better understand and predict planning operations, assist with failure investigations and conduct root cause analysis (RGU, 2016). More recently, a machine learning-based analysis system called Petroleum Analytics Learning Machine (PALM) was introduced for simultaneous real-time analysis of hundreds of IoT attributes from hundreds of horizontal wells, encompassing thousands of hydraulic fracture stages (Anderson, 2017). Such collaborations also portray the increasing demand for Big Data analytics within the O&G industry.

6. Conclusion

Previous research has outlined and concisely summarised the importance of technology and innovation for sustaining the P&P industry, both from an industry and academic perspective (Hassani *et al.*, 2017). In contrast, this paper focused entirely on the influence of Big Data on the P&P industry. The paper began with an overview of Big Data and a discussion around the general importance of same for the P&P industry. Thereafter, it considered the applications of Big Data in upstream, midstream and downstream operations, prior to considering its future potential. The timeliness and importance of this research is evident given that oil is the most traded commodity in the world (Slav, 2017) and that advanced data analytics used by Google, Facebook and Amazon to disrupt consumer-facing businesses are now increasingly applied within the energy industry (Crooks, 2018). The secondary research uncovers some interesting insights in terms of the applications and potential for Big Data within the P&P industry.

Interestingly, the upstream sector appears to be exploiting Big Data and related technologies to the hilt while the midstream and downstream sectors are lagging behind. There are still some positives as the P&P industry is notorious for lagging behind other heavy industries in terms of the speed of adopting new technologies (Endress, 2017). Thus, the upstream sector embracing Big Data sends out positive signals not only to midstream and downstream operations, but the entire industry. It is also evident that there appears to be a trend of inventions such as sensors initially enabling the generation

of Big Data within the industry. Increasingly, Big Data is now motivating further innovations in sensors and Big Data-related technologies which not only enables the analysis of this growing information but also continues to make Big Data grow.

Overall, it is important to bear in mind that the role of Big Data in the P&P industry goes far beyond efficiency gains and real-time analysis, as near-real-time visualisations, data storage and near-real-time alerts are the most important advantages stemming from the adoption of Big Data analytics (Zaidi, 2018). This research intends to concisely summarise the progress made by the P&P industry thus far, in the hope of motivating academics, researchers and industry professionals to invest in further research and development to better exploit Big Data for enhancing the P&P industry and its longevity as a leading sector across the globe.

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