Matthew N. O. Sadiku, 2024, 12:5
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology

An Open Access Journal

Big Data in the Oil & Gas Industry

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Abstract- With the recent introduction of data recording sensors in exploration, drilling, and production processes, the oil and gas industry has transformed into a massively data-intensive industry. These data can come from sensors, data recording devices, spatial and GPS coordinates, weather services, and seismic data. Since the data recording devices and sensors are different in types, the generated data can be in different sizes and formats. The vast quantity of data is challenging to be handled due to storage, sustainability, and analysis issues. The main application of big data is to provide processing and analysis tools for the increasing amounts of data. Big data analyzes huge data sets to reveal the underlying trends and help the engineers forecast the potential issues. This paper reviews the utilization of big data and data analytics in the oil and gas industry

Keywords- big data, big data analytics, oil and gas industry, petroleum industry

I. INTRODUCTION

The world has seen a digital revolution where more and more work is being conducted online. Storing this activity has led to the concept of big data, i.e., large datasets that are otherwise difficult to manage. Because of these characteristics, big data requires new technologies and techniques to capture, store, and analyze. The cloud word for big data is shown in Figure 1 [1]. Typical sources of big data are shown in Figure 2 [2]. Big data is of great interest to oil and gas production and operation. With the advent of new technologies, there has been a massive increase in the amount of data generated within oil and gas sector.

The oil and gas sector is one of the largest and most complex industries in the world, involving the exploration, extraction, refining, and distribution of hydrocarbon resources. The complexity of the O&G operation is illustrated in Figure 3 [3]. With the recent advent of data recording sensors in exploration, drilling and production operations, oil and gas industry has become a massive data intensive industry. There are ample opportunities for oil and gas companies to use big data to get more oil and gas out of hydrocarbon reservoirs, reduce capital and operational expenses, increase the speed and accuracy of investment decisions, and improve health and safety while mitigating environmental risks. Big data can be used to improve decision-making and operational efficiency by analyzing the data to uncover patterns and correlations. Other new technologies such as deep learning, cognitive computing, and augmented and virtual reality can be used to extract useful information enormously reducing the data processing time.

Big data in oil and gas (O&G) is one of the prominent technologies that are now disrupting the industry with innovative methods. It gives businesses and business owners a huge potential to move forward and grow. More industry executives believe that big data is the solution to boost their business operations. For example, major O&G companies like ExxonMobil, BP, and Shell heavily

invest in big data and AI solutions. The companies that embrace and implement new technologies are positioning themselves as frontrunners in shaping the industry's future landscape. To make high profits, these companies must make an environment-friendly commitment and apply IoT for price and asset monitoring.

II. WHAT IS BIG DATA?

Big data applies to data sets of extreme size (e.g. exabytes, zettabytes) which are beyond the capability of the commonly used software tools. It involves situation where very large data sets are big in volume, velocity, veracity, and variability [5]. The data is too big, too fast, or does not fit the regular database architecture. It may require different strategies and tools for profiling, measurement, assessment, and processing.

Big Data is essentially classified into three types [6]:

1. Structured Data
This is highly organized and is the easiest to work with. Any data that can be stored, accessed, and processed in the form of fixed format is known as a structured data. It may be stored in tabular format. Due to their nature, it is easy for programs to sort through and collect data. Structured data has quantitative data such as age, contact, address, billing, expenses, credit card numbers, etc. Data that is stored in a relational database management system is an example of structured data.

2. Unstructured Data
This refers to unorganized data such as video files, log files, audio files, and image files. Any data with unknown form or the structure is classified as unstructured data. Almost everything generated by a computer is unstructured data. It takes a lot of time and effort required to make unstructured data readable. Examples of unstructured data include Metadata, Twitter tweets, and other social media posts.

3. Semi-structured Data
This falls somewhere between structured data and unstructured data, i.e., both forms of data are present. Semi-structured data can be inherited such as location, time, email address, or device ID stamp. The different types of big data are depicted in Figure 4 [7].

The process of examining big data is often referred to big data analytics. It is an emerging field since massive computing capabilities have been made available by e-infrastructures [8]. Analytics include statistical models and other methods that are aimed at creating empirical predictions. Data-driven organizations use analytics to guide decisions at all levels. Several techniques have been proposed for analyzing big data. These include the HACE theorem, cloud computing, Hadoop, and MapReduce [9].

Characteristics of Big Data
Big data is growing rapidly and expanding in all science and engineering, including physical, biological, and medical services. Different companies use different means to maintain their big data.

As shown in Figure 5 [10], big data is characterized by 42 Vs. The first five Vs are volume, velocity, variety, veracity, and value [2].

Volume
This refers to the size of the data being generated both inside and outside organizations and is increasing annually. Some regard big data as data over one petabyte in volume.

Velocity
This depicts the unprecedented speed at which data are generated by Internet users, mobile users, social media, etc. Data are generated and processed in a fast way to extract useful, relevant information. Big data could be analyzed in real time, and it has movement and velocity.

Variety
This refers to the data types since big data may originate from heterogeneous sources and is in different formats (e.g., videos, images, audio, text, logs). BD comprises of structured, semi-structured or unstructured data.

Veracity
By this, we mean the truthfulness of data, i.e. weather the data comes from a reputable, trustworthy, authentic, and accountable source. It suggests the inconsistency in the quality of different sources of big data. The data may not be 100% correct.

Value
This is the most important aspect of the big data. It is the desired outcome of big data processing. It refers to the process of discovering hidden values from large datasets. It denotes the value derived from the analysis of the existing data. If one cannot extract some business value from the data, there is no use managing and storing it.

On this basis, small data can be regarded as having low volume, low velocity, low variety, low veracity, and low value. Additional five Vs has been added [11]:

Validity
This refers to the accuracy and correctness of data. It also indicates how up to date it is.

Viability
This identifies the relevancy of data for each use case. Relevancy of data is required to maintain the desired and accurate outcome through analytical and predictive measures.

Volatility
Since data are generated and change at a rapid rate, volatility determines how quickly data change.

Vulnerability
The vulnerability of data is essential because privacy and security are of utmost importance for personal data.

Visualization
Data needs to be presented unambiguously and attractively to the user. Proper visualization of large and complex clinical reports helps in finding valuable insights.

Instead of the 10V's above, some suggest the following 5V's: Venue, Variability, Vocabulary, Vagueness, and Validity) [12].

Industries that benefit from big data include the healthcare, financial, airline, travel, restaurants, automobile, sports, agriculture, and hospitality industries. Big data technologies are playing an essential role in farming: machines are equipped with sensors that measure data in their environment. Structured and unstructured data are generated in various types [13-15].

III. OIL AND GAS INDUSTRY

Oil is difficult to locate. The oil reservoirs are typically found 5,000 to 35,000 feet below the earth's surface, making them hard to find. Oil is an expensive commodity, and a lot of science, engineering, and workforce are required to produce oil. Given the cost, quantity, and availability of oil, the companies involved in this industry must identify methods to stay profitable. Big data analytics has benefited the oil and gas industry in many ways.

The oil industry divides into upstream, midstream, and downstream, as shown in Figure 6 [16] and explained as follows:

1. Upstream Sector
The upstream process in oil and gas operations refers to the discovery and production of oil and gas . Many activities are done in the upstream area, wherein big data analytics plays a crucial role. Among all business segments upstream segment is the most dominant segment owing to increasing use of big data analytics for the discovery of non-conventional shale gas.

Upstream analytics begins with the collection of seismic data with sensors across a potential area of interest looking for petroleum sources. Then the data is aggregated, cleaned, processed, and analyzed to choose the best location for drilling. Figure 7 show the upstream operation [17].

2. Midstream Sector

The midstream activities in the oil and gas industry refer mainly to the transportation of oil and gas, i.e., logistics. Big data analytics is used to enhance shipping performance. For example, to improve the performance of ships and reduce greenhouse emissions, big data analytics helps by predicting the propulsion power. Big data analytics is essential for planning pipelines and infrastructure to transport oil from sources to refineries and pumping stations. Its significance in logistics makes it a critical tool for oil and gas companies, given the highly flammable nature of the transported material.

3. Downstream Sector

The downstream is responsible for refining petroleum products and delivering them to end-users. It mainly involves refining and selling oil and gas. It is expected to be the second largest segment due to increasing use of product analytics solution which assist refineries to standard chemical composition of the finished products. The downstream oil and gas industry is undergoing a significant transformation due to the integration of dig data technologies. The sector is leveraging big data in numerous ways to enhance efficiency and sustainability.

Plenty of raw information is available for analysis in the oil and gas industry. Whether you are involved upstream, midstream, downstream, administration, or the commodities market, you are surrounded by data.

IV. APPLICATIONS OF BIG DATA IN OIL AND GAS

The oil and gas industry is no stranger to data. For decades, it has generated massive volumes of information from exploration, production, and distribution operations. The recent technological improvements have resulted in daily generation of massive datasets in oil and gas exploration and production industries. Big data in the oil and gas industry is the massive amount of data generated by various processes and transactions in the sector. The advent of modern sensing technologies, such as the Internet of things (IoT), and remote satellite monitoring, has created an explosion in data generation throughout the sector. Figure 8 shows data analytics in oil and gas sector [16], while Figure 9 shows the key components of big data analytics in oil and gas industry [18]. Here are some ways big data is used in the oil and gas industry [19,20]:

1. Supply Chain Optimization

One key area of application is supply chain optimization. By optimizing logistics, tracking inventory levels, and improving distribution efficiency, downstream companies reduce operational costs while minimizing waste--thus ensuring that products reach customers in a timely manner. Big data can help optimize supply chains by analyzing data on inventory, transportation, demand, and market trends. Data-driven demand forecasting models help companies manage their inventories, optimize logistics, and make informed decisions for both upstream and downstream operations.

2. Assessing New Prospects

Competitive intelligence is created using analytics applied to geospatial data, oil and gas reports and other syndicated feeds in order to bid for new prospects.

3. Enhanced Oil Recovery

Enhancing oil recovery from existing wells is a key objective for oil and gas companies. Analytics applied to a variety of big data at once (seismic, drilling, and production data) could help reservoir engineers map changes in the reservoir over time and provide decision support to production engineers for making changes in lifting methods. This type of approach could also be used to guide fracking in shale gas plays.

4. Real-time Production Optimization

Real-time SCADA and process control systems combined with analytics tools help O&G producer to optimize resource allocation and prices by using scalable compute technologies to determine optimum commodity pricing. They also, help to make more real time decisions with fewer engineers. Big data can be used to monitor and analyze production processes in real time, which

can help identify bottlenecks and predict equipment failures.

5. Prevent Cyber-Terror Acts

Oil companies need to identify events or patterns that could indicate an impending security threat or cyber-terrorist act in order to keep their personnel, property and equipment safe. Predictive analytics is central part of identifying patterns that can help detect these threats beforehand.

6. Data Crunching

From wells, digs, and extraction to transportation and refining, there are ample opportunities to collect data on every single aspect of your business operations. Investing in machine learning will help a company absorb petabytes of sensor data from drills faster than a whole fleet of workers on the actual job site. This frees up the people to make better, more informed decisions.

7. Predictive Analysis

Algorithms can use historical data and experience to make better and more enlightened predictions about future operations. Companies in possession of this level of enhanced analysis can use it to make very educated guesses about future trends, prices, production, and actions in the market. The more you understand what could happen with your industry, the better prepared you will be for any contingency.

8. Decision-Making

Data plays a critical role in the decisions that create value. Today, data analytics is being leveraged throughout the oil and gas value chain to optimize decision-making and improve overall performance. Operators make decisions every day in the field, typically with limited involvement by central functions or subject matter experts. With predictive analysis, you can make faster decisions, supported by faster delivery of decision support information, to identify possible threats. You can make the move from educated guesses to confirmed, real-time decisions with ease and confidence. In essence, data analytics does not remove the human element from making decisions. It helps humans make better decisions.

9. Predictive Maintenance

Big Data analytics enable predictive maintenance through IoT devices and sensors deployed in downstream facilities. Predictive maintenance models based on data analysis can proactively identify areas requiring maintenance and reduce equipment failures, leading to optimized operational efficiency and reduced costs. Everyday operations in the oil and gas industry depend upon a substantial amount of machinery. Thus, it is essential for a business to keep tabs on the condition and fitness of its equipment so it can address problems before a shutdown occurs. Advanced analytics can compare the age of a given machine with its rate of past and future usage to determine when it is most likely to need maintenance and replacing.

10. Data Mining

This is the extraction of relevant information and insights from large datasets using statistical and computational methods. Data mining is an integral part of big data analytics, which entails processing, analyzing, and interpreting large and complex datasets to discover patterns, trends, and insights that can assist organizations in making informed decisions. Data cleansing, data validation, data normalization, and data transformation are some of the methods used by data mining and analytics practitioners to reduce the likelihood of these errors.

Figure 1: The cloud word for big data [1].

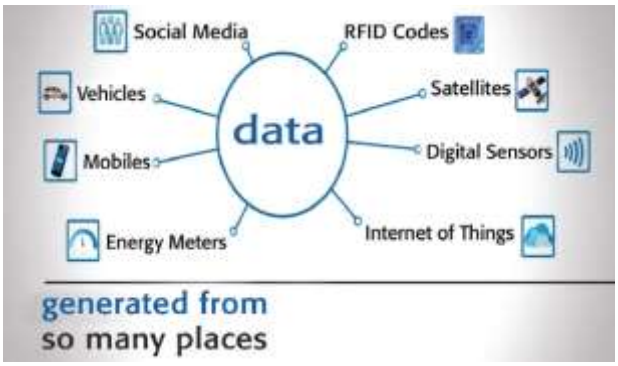

Figure 2: Typical sources of big data [2].

Figure 3: The complexity of the O&G operation [3].

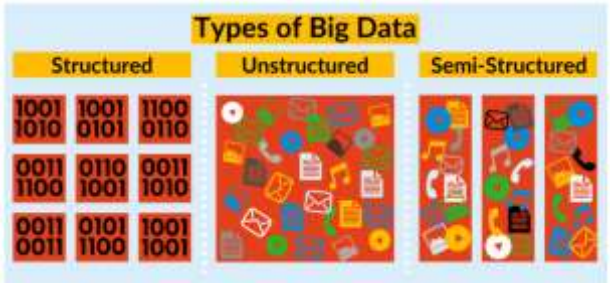

Figure 4: Types of big data [7].

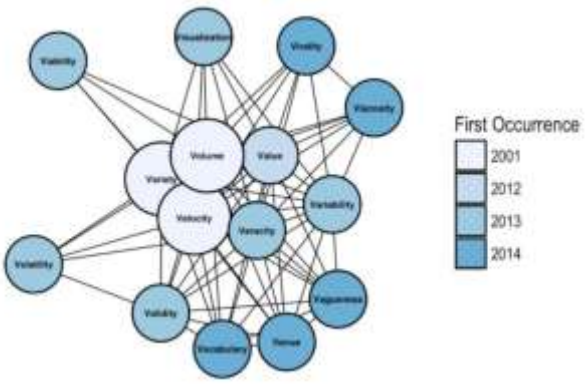

Figure 5: The 42 V's of big data [10].

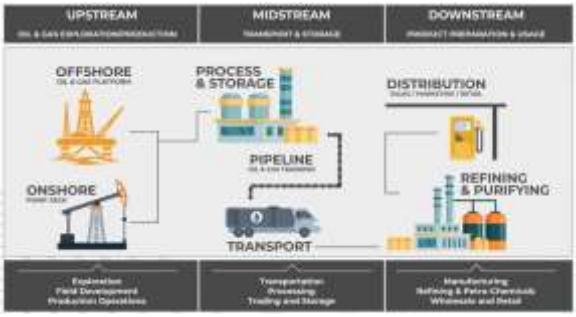

Figure 6: The oil industry divides into upstream, midstream, and downstream [16].

Figure 7: Upstream operation [17].

Figure 8: Data analytics in oil and gas sector [16].

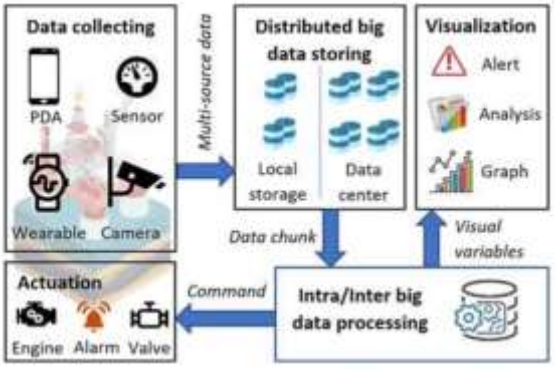

Figure 9: Key components of big data analytics in oil and gas industry [18].

Benefits

Big data is used to identify conditions or anomalies that would impact on drilling operations. Big data solutions can provide companies in the oil and gas industry with insights into exploration, drilling, and production processes to ensure their optimization, reduce environmental risks, streamline equipment maintenance planning, enhance oil recovery, and more. Big data also has other benefits for the oil and gas industry, including the following [21]:

Safety

The responsibility for the health and safety of the individuals working in the oil and gas industry is with the companies that employ them. Big data can be used to monitor for safety hazards and environmental risks, such as leaks, air quality, and pipeline integrity.

Big data analytics helps prevent accidents by predicting and detecting anomalies and issues, such as stress corrosion and fatigue cracks in pipes and trucks, along with early detection of seismic movements.

Cost-Effectiveness

The effectiveness of big data analytics in the oil and gas industry has been widely acknowledged as it has evolved into a crucial instrument for enhancing operational efficiency and lowering costs. When you have access to game-changing information about your operations, it becomes easier to increase the efficiency and efficacy of your projects.

This increase in productivity can be experienced at every level of the oil and gas industry. This streamlined supply chain not only enhances cost-effectiveness but also contributes to a more sustainable operation by reducing the environmental footprint associated with transportation and storage.

Manage Seismic Data

Drilling for oil in deep water can cost over $100 million, and it is crucial that you find the right location. In fact, to avoid any risks and save time and money, Shell uses fiber optic cables and the data is then transferred to its private servers.

Optimize Drilling Process

Today's oil drilling platforms have about 80,000 sensors, which are expected to generate 15 petabytes of data during the lifetime of a platform. The large amount of data gathered by these sensors allows for predictive maintenance of equipment and timely replacements in order to reduce downtime and increase efficiency.

Improve Reservoir Engineering

Big data solutions help oil and gas companies to collect, process, and analyze data that is essential for making reservoir production more effective. They help to collect and process data that O&G companies need to make reservoir production more effective. This data is collected using a number of down hole sensors (temperature sensors, acoustic sensors, pressure sensors, and others). To make energy more affordable and sustainable, we use big data tools to understand the earth's subsurface better.

Improve Logistics

The oil and gas industry faces the problem of safely transporting petroleum. The major problem that concerns logistics in the oil and gas industry is transporting petroleum while reducing risks as much as possible. To ensure that gas and oil are transported safely, companies use sensors and predictive maintenance. Sensors, predictive maintenance, and other technologies help detect any faults in pipelines or tankers. This allows for safe logistics of petroleum products.

Quality

Just as with petroleum data analytics, the use of big data analytics can be instrumental in maintaining consistent product quality. By monitoring and controlling the refining process in real time, companies can ensure that their products meet stringent specifications and safety standards. This proactive approach also enhances customer trust and brand reputation.

Workforce Management

Data-driven insights help employers optimize their workforce strategy and develop training programs tailored to specific job roles and skillsets.

Prescriptive Analytics
By incorporating human expertise and external data sources into AI models, companies can generate detailed recommendations for specific actions and their potential outcomes.

Data Integration
The oil and gas industry has focused on data integration, i.e., how do we get all the data in one place and make it available to the geo-scientists and engineers working to find and produce hydrocarbons. Proper data integration grows more crucial as oil fields mature because operators must understand changing field conditions. Managers know more than anyone that they must maximize hydrocarbon production while reducing drilling costs.

Challenges
The sheer volume, complexity, and speed of data generation in the O&G industry have created both significant challenges and opportunities. Leveraging big data in the oil and gas sector poses challenges, such as data integration from diverse sources, data quality assurance, data privacy, and security concerns, and the need for skilled team to understand and analyze the data. Implementing big data in the oil and gas industry presents challenges related to data transfer, collection frequency, and data quality. They include [21,22]:

Legacy Systems
Many oil and gas firms still rely on legacy systems and outdated technologies, which can hinder the integration and effective utilization of modern data analytics platforms.

Historical Data
The oil and gas industry faces the challenge of handling vast amounts of historical data accumulated over decades. This historical data, often in various formats and from different sources, needs to be integrated and made compatible with modern operations. Accumulated and analyzed historical data of various injury-causing accidents help identify patterns and trends to mitigate the risk of working in this field. Overcoming this challenge requires robust data management strategies and investments in data infrastructure to facilitate seamless data transfer.

Data Integration
Merging data from disparate sources and systems can be a complex and resource-intensive task. The establishment of a unified data model (or data lake) is crucial for successful analytics implementation.

Data Quality
The data available in the oil and gas industry is unique and peculiar. Data quality and accuracy issues are among serious problems that are present in the industry. Ensuring data accuracy, reliability, and timeliness is critical for analytics success, otherwise, the insights drawn might be misleading or even detrimental. Stringent data governance mechanisms and maintaining the data integrity should be prioritized.

Scalability
Oil and gas companies should have scalable analytics infrastructure and agile analytics platforms that can evolve and handle massive amounts of data while adapting to the ever-changing industry landscape.

Talent and Skills
The oil and gas industry has traditionally been an engineering-driven domain, but success in the big-data era requires diverse talents and expertise to navigate the multi-disciplinary landscape of analytics. In addition to that, you need a thorough understanding of the physics of the problem.

High Cost
One of the major challenges of big data's application in any industry including oil and gas industry is the cost associated with managing the data recording, storage, and analysis. There is a high financial cost associated with dealing with data.

This includes various data management activities such as data recording, storage, maintenance, and analysis. A huge investment is involved in the infrastructure of energy pipelines; hence its integrity is a must for reliable operations.

V. CONCLUSION

Big data is the idea that some aspect of your business operations generates large amounts of information, and you need to figure out what to do with it. No matter how entrenched in the "old ways" a company might be, now is the time for the entire oil and gas industry to embrace the benefits of big data analytics. Since O&G companies create lots of information, it makes sense to find new and improved ways to put that information to the best possible use.

The integration of advanced analytics and the increasing reliance on big data are driving the oil and gas sector toward a future where fully autonomous control systems for complex processing facilities become a reality. The future of big data in the oil and gas industry is promising, with the potential to drive efficiency, safety, and sustainability. However, realizing these benefits requires careful planning, investment, and a commitment to addressing challenges such as data security and integration. More information about big data in O&G operations can be found in the books in [23-29] and the following related journals:

- Petroleum
- Energy Reports
- Oil & Gas Journal

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