

**Moving forwards in a changing industry: A historic
review of industrial revolutions within a changing
industry. How the upstream oil and gas industry can
benefit from IR4.0 technology adoption and employee
perceptions to IR4.0 technology with an SME.**

By

James Scorgie

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DECLARATION

NAME: James Scorgie

STUDENT NUMBER: 2113853

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Abstract (Executive Summary)

The oil and gas industry is one of the largest and most controversial industries in the world, in some ways the oil and gas industry is opposed to Industry 4.0 principles (circular economy and strive towards net-zero). However, Industry 4.0 is key in ensuring that whilst oil and gas is needed, that upstream exploration for oil and gas is conducted in a way that maximises efficiency.

The objective of this study is to review historical changes in the oil and gas industry from previous industrial revolution, and to review how the current Fourth Industrial Revolution is impacting the oil and gas industry in the upstream sector.

Furthermore, the employee perceptions towards Industry 4.0 are unknown within the upstream oil and gas sector, with no known literature published on the subject. This study will use a survey sent to employees within an upstream oil and gas consultancy to evaluate perceptions towards IR4 adoption using a Likert style survey.

Finally, a short review of barriers towards Industry 4.0 technology adoption will be performed using existing literature from selected research papers and web articles.

The study found that previous industrial revolutions had a profound impact on the oil and gas industry, without them the industry would not be what is today and arguably key technological advances in history (such as the personal automobile) would not have been possible, nor widely accessible.

IR4 is found to already be impacting the upstream sector within the oil and gas industry, mainly in examining old 'big datasets' and integrating AI in producing models for geologists. Further technology such as the internet of things and digital twins are being used to forward predict maintenance and design infrastructure.

Perceptions towards in the upstream consultancy generally found that the attitude of employees was mostly positive towards Industry 4.0 technology and principles, although there was a lack of prior knowledge of Industry 4.0 before the study. Employee perception and fear of job losses was found to be one of the key concerns from reviewed literature towards the adoption of Industry 4.0 technology and processes.

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Notice of non-publication:

Please note that this dissertation contains sensitive information from PetroStrat LTD. This dissertation report should not be published publicly without prior written approval from PetroStrat management.

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1 Introduction

Industrial revolutions have been crucial forward steps in the world fuelling global industrialisation, innovation and growing the global connected economy in the past 200 - 300 years. Since the early days of the first industrial revolution, fuel and access to cheap energy have been two major factors in why regions/countries are able to progress quickly with technological adoption and improvement.

Whether it be in the form of burning coals or harnessing river power for water wheels, energy innovations have been at some of the forefronts of the world's industrial revolutions/industrial innovation and will continue to be a focus moving forward, especially in a world that is seeking to become more energy efficient and ultimately carbon neutral. Industry 4.0 (also known as: IR4, Fourth Industrial Revolution, IR-4) is the fourth industrial definition as defined recently by Gilchrist (2016).

So, what is the Fourth Industrial Revolution? The Fourth Industrial Revolution can be summarised as global advances and adoption in: additive manufacturing (3D printing), AI (artificial intelligence), big data and live analytics (dashboarding), block-chain technology, cloud, industrial internet spaces, and simulation (Bai et al., 2020, 2017; Dalenogare et al., 2018; Gilchrist, 2016a), a full list and definitions of emergent Industry 4.0 technologies can be found in Bai et al. (2020). More recently, there have been reports of an impending 'Fifth Industrial Revolution' Industry 5.0 from the European Commission that focusses on the relationship between AI and humans in the workplace – Figure 1 gives a summary of the key technologies that Industry 4.0 revolves around. This is a relatively recent, and hugely contested area of technology/innovation, with major morale and ethical concerns (Özdemir and Hekim, 2018; Skobelev and Borovik, 2017; Xu et al., 2021). However, this research paper will include Industry 4.0 and Industry 5.0 together as they represent continuations of another as opposed to major step changes as seen in the first three 'Industrial Revolutions'.

Industry 4.0 can be summarised into 7 key pillars (Figure 1): Internet of Things (IoT); Big data and associated analytics; Artificial intelligence and Machine Learning

(neural networking); cyber physical systems; 3D printing (additive manufacturing); cloud computing; AR and VR (augmented reality and virtual reality).

1 – Internet of Things (IoT) is a concept that originates from the late 1990s, where physical items would be connected to the internet and each other by connected to each other by sensors or networked tags. Whilst not a new concept, Industry 4.0 combines modern advances in cloud computing and AI to allow for sensors to automatically talk, communicate and even make decisions without human intervention (Gilchrist, 2016b; Kramp et al., 2013; Rose et al., 2015).

2 – Big Data and Analytics refers to the use of structured, semi-structured and unstructured datasets that exist within companies. Big data is often utilised in artificial intelligence for training datasets and to mine old data (analytics) for new interpretations using automated methods. Big data is often defined as big data based on the 3 'big V's: volume, velocity and variety. To be considered big data, data will come in higher volumes, higher velocity and varieties compared to traditional structured datasets (Olneva et al., 2018; Ularu et al., 2012).

3 – Artificial intelligence and machine learning is not a new concept. Artificial intelligence (AI) means to implement tasks or systems to perform tasks that usually require a human input, such as visual perception, speech recognition, decision making and translation between languages (as some examples). AI can be considered as a set of technological systems to solve a complex problem traditionally only capable of being solved by a human (Fetzer and Fetzer, 1990; Kaplan, 2016; PK, 1984). Machine learning (ML) is an extension of this, that allows for machines to automatically learn and improve based off experience, or to predict an outcome based on experience. As machine learning models are exposed to more data over time, the more accurate they will become (Alpaydin, 2021; Sircar et al., 2021).

4 – Cyber physical systems refers to the process of integrating computational and physical processes, to make automated and intelligent self-regulating processes. This is often an extension of combining AI/ML with the internet of things. Whilst traditionally control systems would only perform a task pre-programmed, cyber-physical systems combined with AI would allow for computers to make decisions based on the data being fed, in context this allows cyber-physical systems to react quicker to changing circumstances in manufacturing contexts than a human could (Alur, 2015; Putnik et al., 2019; Wolf, 2009).

5 – 3D printing (additive manufacturing) is the process of building physical objects, based on digital models and then actively printing them using a '3D printer' that uses resin or other materials to build an object layer by layer. The process is used commonly for prototyping/test of experimental products or parts, or for the retrofitting (retro-manufacture) of parts that are difficult to source. 3D printers have been designed to work with a variety of materials, from plastic resins to concrete (Shahrubudin et al., 2019; Su and Al'Aref, 2018; Zukas and Zukas, 2015).

6 – Cloud computing/Cybersecurity is the application of having access to a shared pool of computing resources 'in the cloud' using the internet. Traditionally large computing power was difficult and expensive to access for all but the larger companies, however, with the growth of cloud servers this technology has become accessible to all. Due to the nature of cloud computing, resources can be shared or only used when required – reducing the costs to companies (Lin et al., 2009; Park, 2018). Cloud computing also allows for global viewing of data across several different countries/offices/companies (Yang et al., 2017). As data stored in the cloud is accessed via the web, it is important that cybersecurity is taken seriously to keep data secure.

7 – AR and VR (augmented reality and virtual reality) are similar and often confused. Augmented reality (AR) enhances the real world with computer-

generated data (for example, augmenting data over valves/sensors), whilst virtual reality (VR) refers to creating entirely computer generated/simulated environments (Craig, 2013). VR can be combined with simulations and big data to create virtual models referred to as 'digital twins' which can be used to model processes or prototype in the virtual space (Havard et al., 2019; Wohlgenannt et al., 2020).

Industry 4.0 is very much a **BUZZWORD**, however, like many buzzwords there is substance behind the word. Lia Tirabeni a lecturer at the University of Turin best sums up Industry 4.0 by saying in an interview "Innovation is the trigger of Industry 4.0" (R&D Today, 2019) – it is a collection of wider technologies that coming together could mean for stronger & connected systems and processes within companies (something that would not have been possible prior to modern technology).

Like Industry 4.0, innovation could be considered a buzzword – but it can be so much more. Without innovation, there would have been no industrial revolutions, no Apple iPhones and aeroplanes to name just a few. Industry 4.0 and the technology associated with it can help with unlocking innovation processes within companies.

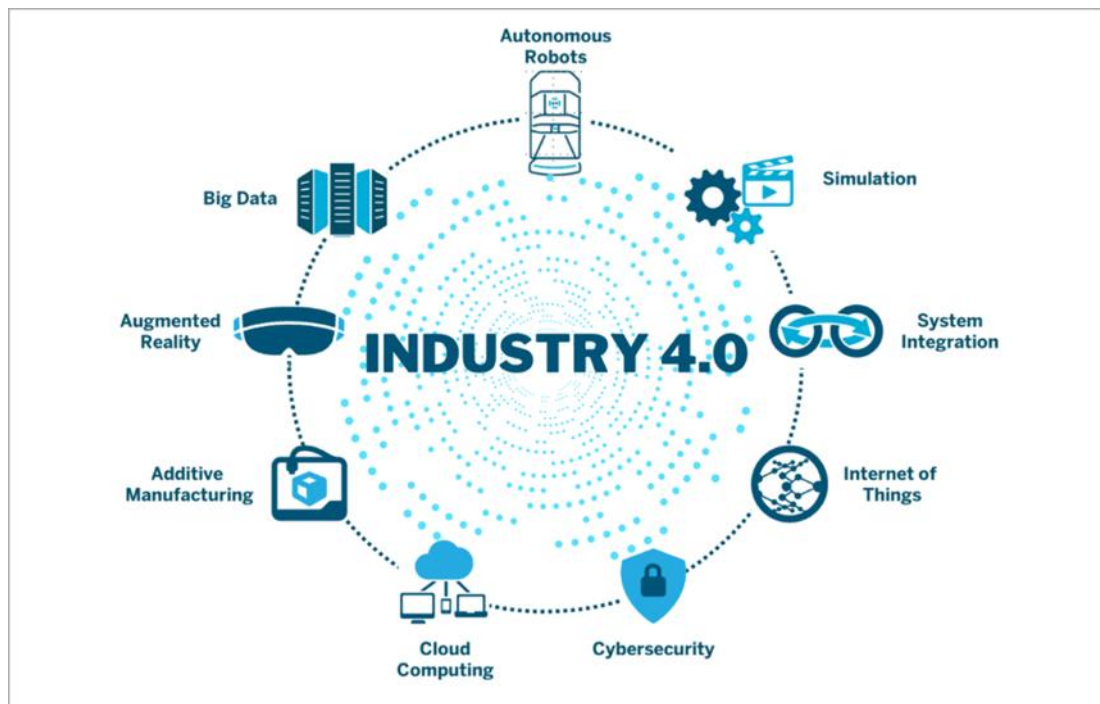


Figure 1 – Showing the key cornerstone technology and processes surrounding Industry 4.0

1.1 Aims and Objectives

The aims of this study are twofold, first to review the historic impacts of previous Industrial Revolutions on the oil and gas industry, and future impacts that new Industry 4.0 developed technology/innovations will have. And secondly, to review the future impacts of Industry 4.0 technologies on the Upstream sector & whether the industry is doing enough to incorporate Industry 4.0 principles and ultimately encourage innovation.

Secondly, data acquired from the survey employees of a SME Geological Consultancy based in North Wales will be used to examine employee perceptions of the adoption of Industry 4.0 technology within an Upstream Oil and Gas consultancy.

In summary the aims are:

- What are the historical impacts of previous industrial revolutions on the oil and gas industry?
- What are current developments in the oil and gas industry surrounding Industry 4.0 technology?

- What opportunities are there for Industry 4.0 technologies in the Oil and Gas sector?
- What are the perceptions of Industry 4.0 technology and adoption using views of a SME consultancy?
- What are the barriers to Industry 4.0 adoption within companies?

1.2 Justification

The justification for the chosen topic of evaluating Industry 4.0 technology in the oil and gas industry are due to the following facts:

- Oil and gas commodities make up over 3.8% of the world's global GDP (Stevens, 2018; The Investopedia Team, 2023), with that figure often higher in countries that rely on oil and gas as their main source of income such as Libya (56.4% of GDP), Iraq (42.8% of GDP) and Republic of Congo (34.4% of GDP) (World Bank, 2023).
- Carbon sustainability and reduction of emissions as well as the transitioning to greener energy sources is one of the key challenges that Industry 4.0 faces compared to previous industrial revolutions (Birkel et al., 2019; Furstenau et al., 2020; Kaya et al., 2020), with the development of circular economy principles/processes being at the forefront of Industry 4.0 principles (Rajput and Singh, 2021).
- Oil and gas is becoming a scarce commodity (Maugeri, 2012), and exploration for new reserves is becoming increasingly difficult as more technologically or politically challenging oil reserves are explored as traditional 'less complicated' reserves are depleted. Industry 4.0 could help to understand and unravel some of the complexities of modern-day oil exploration.

Whilst many people would be of the opinion that Industrial Revolutions should only consider 'newer' technology, it is important to remember that currently 80% of the world's energy comes from oil and gas (Epstein, 2022). Whilst the future looks set to change as efforts are pushed towards changing to renewable energy, it is vital to make the most of our current fossil fuel consumption in order to minimise unnecessary carbon emissions, whether that be: efficiency gains (from less waste in production and use of fossil fuels); circular economy processes (i.e. eliminating single use plastics, stopping flaring, etc.); or from using the metaverse to speed up processes (e.g. VR, AR and MR technologies).

1.3 Methodologies and material sources

1.3.1 Methodology

This research study will predominantly take the form of two parts: the first (Chapters 2 – 4) being a literature review of historic oil and gas exploration, uses, historic industrial revolutions and current Industry 4.0 usage/adoption. Findings will be synthesised by the author using a range of contrasting reference material (discussed in Chapter 1.3.2), that will try to bring contrasting views to the attention of readers to provide a balanced view of subjects.

The second part of the survey (Chapters 5 – 6) will explore the perceptions of Industry 4.0 using a survey of employees of a SME consultancy operating in the energy consulting sector (predominantly oil and gas) to evaluate employee perceptions to Industry 4.0 technologies globally and internally. This will then be integrated with a short review of literature exploring the barriers to innovation within oil and gas companies (although, this could be applied to companies overall).

1.3.2 Reference material sources

Reference sources discussed in this paper are sourced from reputable literature sites such as Google Scholar (<https://scholar.google.com/>) and the Web of Science (<https://mjl.clarivate.com/home>). Both sites allow for a wide range of current relevant journals and books to be searched through, as well as filtering for specified data ranges and keywords – books will be accessed digitally through the University Library (UWTSD Library - <https://www.uwtsd.ac.uk/library/>) or in person from the University of Liverpool's libraries (Harold Cohen or Sydney Jones in Liverpool). Occasionally webpages (such as industry news pages, news reports or company websites) may be referenced, however, this will be avoided where possible as webpages are not subject to the same review process as journals.

In section 5, a survey was used to collect data from employees of a SE consultancy operating in the oil and gas sector for responses. These respondents were from company employees only.

1.4 Research limitations

The limitations of the literature review in this study are constrained by the fact that Industry 4.0 knowledge and application is a recent innovation, therefore there is always more literature being published surrounding the topics discussed in this study. Due to this, it is likely that some of the literature review may be outdated at the time of publication, however, the conclusions and recommendations on how companies can apply Industry 4.0 and the perceptions that their employees may have towards Industry 4.0 should remain robust.

The limitations of the survey performed in this research are mainly due to the limits of the sample size of the survey conducted. Sample size calculations have been devised in the past, notably by Das et al. (2016) and Hsieh et al. (1998) – Table 1 shows how large survey populations need to be when applying the results of a survey to a wider population group. Within PetroStrat there are ~120 full time equivalent employees (FTEs), therefore for a statistical margin of error of 5% a survey size of ~85 is required. A total of 45 surveys were returned from staff, representing approximately 40% of the entire staff population. Sadly this is not enough to ensure that a 5% margin of error is achieved, however, using the calculations given by Hsieh et al., 1998 – it is calculated that for a survey size of 45 employees, there is a 10% margin of error with 90% confidence. This is adequate for the population size and intended use of the study. Furthermore, as PetroStrat LTD only operate within the upstream area of oil and gas and perform a consulting role, it may be difficult to compare any survey results from this study with other companies outside the upstream consulting environment.

Table 1 - Sample sizes required for reducing margins of error when comparing to wider population groups
(Table source: Yaw Obeng et al. (2011).

Population	Margin of Error			
	5%	3%	2%	1%
50	44	48	49	50
100	79	91	96	99
150	108	132	141	148
200	132	168	185	196
250	151	203	226	244
300	168	234	267	291
400	196	291	434	384
500	217	340	414	475
750	254	440	571	696
1,000	278	516	706	906
2,000	322	696	1091	1655
5,000	357	879	1622	3288
10,000	370	964	1936	4899
100,000	383	1056	2345	8762
1,000,000	384	1066	2395	9513
10,000,000	384	1067	2400	9595

1.5 Research ethics

Due to the current political and social attitudes towards the oil and gas industry, especially with the widely acknowledged increase in global temperatures worldwide because of burning fossil fuels – it is important to consider the ethical implications of this study. This research has not been sponsored or encouraged by any business operating within the oil and gas industry or by any other interested third party and is entirely organic to the researcher. However, support has been provided to the researcher in the form of time to complete the research during working hours as part of their employment – but has in no way influenced this research or the outcomes of it.

Data were collected from employees via an anonymous survey for the purposes of this research, however, it was clearly stated that any responses were entirely voluntary and completed with consent by employees in their own time without any external pressure from the researcher or their employer's. Likert analysis guidance given by Barua (2013) and Batterton & Hale (2017) were used to ensure that the survey questions did not lead the participant into answering one way or another.

The researcher hopes that by completing this research, it will allow companies to better understand employee perceptions towards Industry 4.0 and how it may impact any future technology rollout.

Any literature reviewed during this report will include references from a wide range of authors of contrasting views and schools of thoughts. Any media or work used in this study will be correctly cited & sourced, and the author will avoid any plagiarism by referencing appropriately using the commonly used Harvard (Elsevier) citation style as outlined by Gray et al. (2008) in order to maintain academic integrity and allow for free flowing discussion within the paper.

As part of the company survey for this study, people surveyed were given the option to be entered into a raffle draw for a Toblerone, in which two winners would be randomly drawn from the respondents of the survey. Respondents were required to complete all questions, survey completion time is consistent between respondents who chose to take part in the raffle for the Toblerone bars and those who didn't indicating that respondents did take their time completing the survey and that there were no 'run and gun' respondents who quickly responded with the intention of only entering the raffle.

2 Introduction to the oil and gas sector

This section will give a brief introduction to the oil and gas sector for the non-specialist, the uses of oil and gas and the future moving forwards.

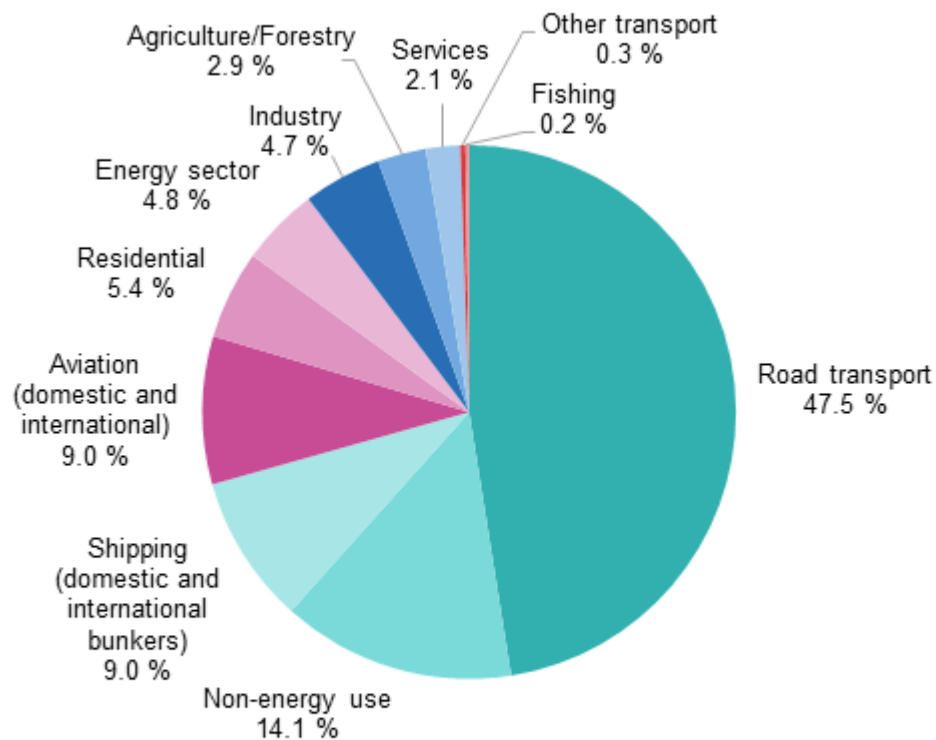
Oil and gas is traditionally the large political 'elephant in the room', however, without a drastic change in renewable policy it is unlikely that oil and gas use will stop any time soon. Berners-Lee and Clark (2013) discuss this in detail, following record breaking temperatures in the USA in 2013, however, since then temperatures have continued to rise. Recent reports by Ripple et al. (2023) and a very recent article by Li et al. (2024) in January 2024 confirms that 2023 is the hottest since records began, more than 10 years since Berners-Lee & Clark's book was released.

It is therefore important that whilst we need to reduce the emissions from fossil fuels such as oil and gas – we also need to rethink its use as a resource and why we will still need oil and gas in the future.

2.1 Uses of oil and gas

The uses of oil & gas are wide-ranging and are far beyond that than just filling at the petrol pumps – which is arguably the most visible use of oil and gas in the form of products such as petrol (gasoline) or diesel for our vehicles.

Consumption of oil in selected sectors, EU-27, 2018
(%)



Source: Eurostat (online data code: nrg_bal_c)



Figure 2 - Uses of oil and gas across the EU 27 countries. Note that as the EU comprises mostly more-economically developed countries, these proportions. Non-energy use refers to a wide ranging category that includes plastics and petrochemicals. Source (Eurostat, 2023).

Despite road transport (including domestic and commercial use) taking up 47.5% of usage within the EU according to EuroStat (Figure 2). Transport accounts for over 65% of usage overall (Figure 2), however, there are still a wide range of other uses of oil and gas that the average person would not think about.

Whilst plastics are widely thought to be another oil and gas product from petrochemicals, these only account for 4% of total oil and gas usage (British Plastics

Federation, 2024; Jefferson, 2019). Plastics (especially single use plastics) have also been the subject of widespread debate in recent times, with areas like the Great Atlantic Garbage Patch fuelling debate – see <https://education.nationalgeographic.org/resource/great-pacific-garbage-patch/>. In 2015 a YouTube video released by 'Sea Turtle Biologist' (2015) brought further attention globally, with the footage of a sea turtle having a single use plastic straw removed from its nose. Research has since linked single-use plastics with increased mortality rate of sea turtles (Müller et al., 2012; Wilcox et al., 2018), with items such as plastic straws and bags being two of the main items ingested by sea turtles. This also led to global political attention brought to single use plastics, with the implementation of either a complete ban on the use of plastic bags and straws in some countries – or a charge for a bag. The UK law changed in 2015 to ensure that all single-use plastic bags were subject to a charge, and whilst at the time this move was considered controversial it has been seen to change attitudes of individuals, encouraging recycling and reuse of plastics outside of single use plastics. Industries have moved away from single use plastics and are now making items as reusable as possible (Thomas et al., 2019), thus seeing the implementation of circular economy principles (one of the cornerstones of Industry 4.0) to the plastics industry and usage (Kurniawan et al., 2022; Massaro et al., 2021; Rajput and Singh, 2021, 2019).

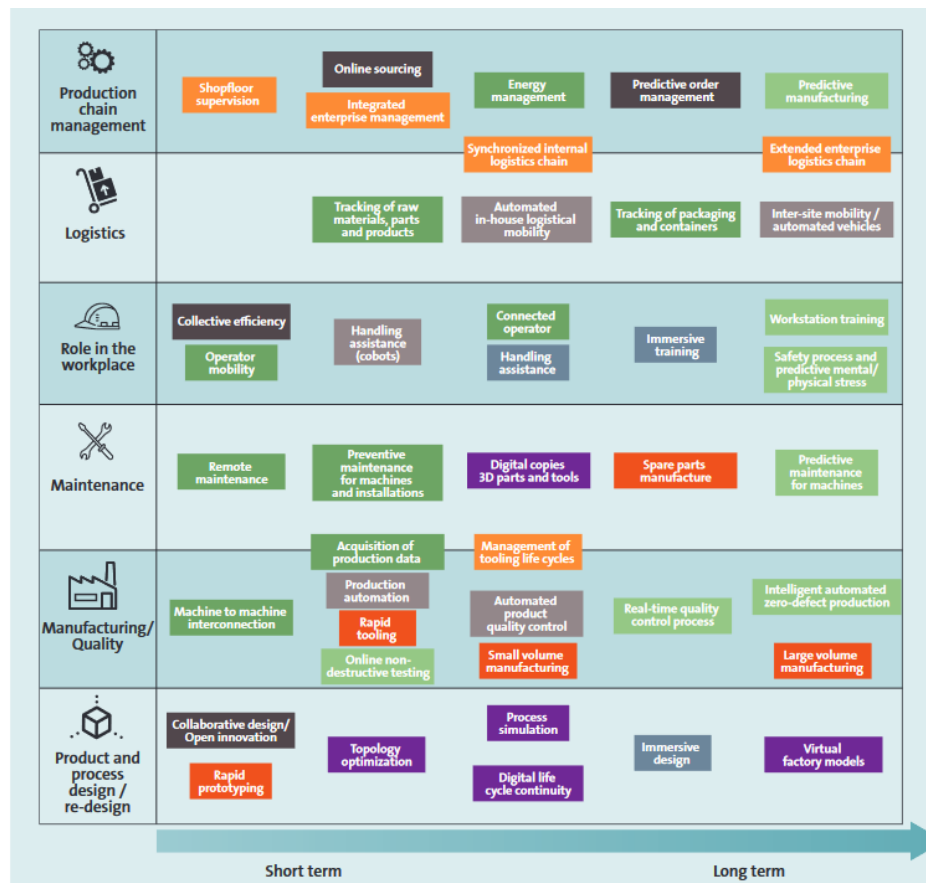


Figure 3 - How the plastics industry is being transformed by the current Industry 4.0 revolution. Source: (Guyot Phung, 2019).

Plastics are just one small part of oil and gas manufacturing that has been revolutionised by Industry 4.0 technology (as shown in Figure 4) and this will be discussed further in section 4.

Along with plastics, there are thousands of other products and chemicals that are derived from petrochemicals. The list would be exhaustive if listed in the entirety of this report, however, a few that may surprise you: toothpastes, dentures, antibiotics, iodine (waste fluid from oil and gas production), antihistamines, paint/dyes, poly-clothing materials, insecticides, fertilizer etc. are some of the products derived from oil and gas (US Department of Energy, 2019). This is one of the reasons that Industry 4.0 must be used to ensure that the most is made of what is an increasingly non-renewable resource.

2.2 Explanation of sectors within the oil and gas industry

The oil and gas industry is composed of three main sectors which are key to understanding the industry, they are: Upstream, Midstream and Downstream (Herkenhoff, 2018; Patidar et al., 2024). Figure 4 shows a simplified diagram of the relationship between each sector and the cascade of initial production to use by consumers.

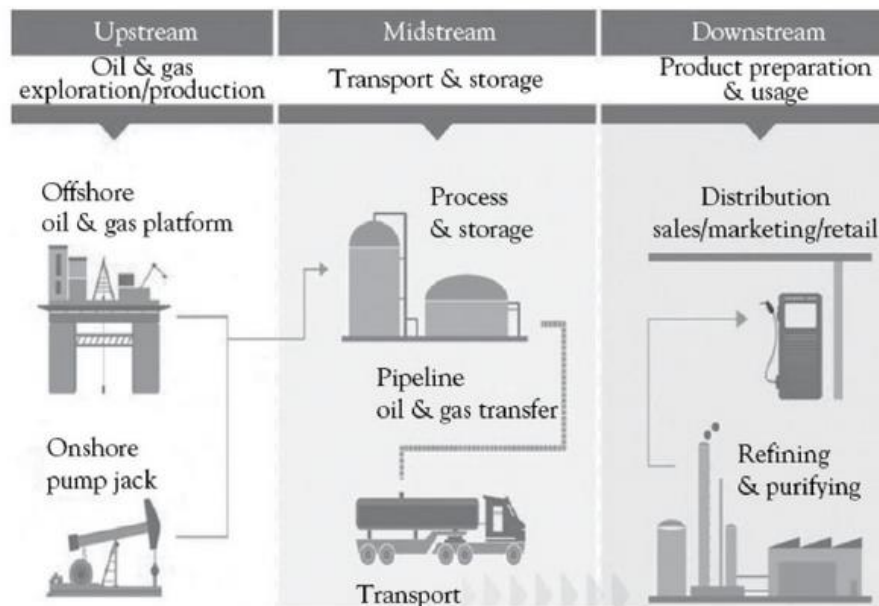


Figure 4 - A simplified diagram of Upstream, Midstream and Downstream sectors. Source: (Herkenhoff, 2018).

Upstream refers to the exploration for oil and gas reserves and all of the activities associated within the sector. This includes initial geological surveying of areas, modelling of oil reserves in place and the eventual drilling (production of reserves). The term is referred to in ISO 14224 (<https://www.iso.org/standard/64076.html>) as “business category of the petroleum industry involving exploration and production” (International Standards Organisation, 2016). This ISO governs the standards around reliability and maintenance data in the upstream sector.

Midstream refers to the transportation, process and storage of raw petroleum products from the place they are produced from (whether this is an offshore oil rig or onshore oil pump). Products are split into their fractions (i.e. gas and oil fluids separated) in preparation for the sale downstream. The term is referred to in ISO 20815 (<https://www.iso.org/standard/69983.html>) as “business category involving

the processing and transportation sectors of petroleum industry” (International Standards Organisation, 2018). The ISO focuses on ensuring product standards in the midstream sector.

Downstream refers to the further refining of oil and gas products, and the marketing and sale of refined products to consumers e.g. petrol sold at a petrol station. The term is referred to in ISO 20815 (International Standards Organisation, 2018) as “business process, most commonly in petroleum industry, associated with post-production activities”, as mentioned previously this iso focuses on ensuring that refined products from the downstream sector meet product standards.

There is a further term that is used in conjunction with these sections, and that is ‘vertical integration’. Whilst like other industries companies may operate in these sectors independently, for example a computer chip manufacturer like Intel may produce processors it would be a company like Dell that put all of the component parts to make a computer: oil and gas can operate in an integrated fashion combining all three sectors. Examples of this include BP and Shell, whom both explore for oil (upstream), transport and store the oil (midstream) and also refine and process the oil (downstream). Whilst vertically integrated companies can operate in each industry sector, there are pros and cons to this that will not be fully discussed in this report.

2.3 Supply and demand impacts on innovation

The supply and demand of oil is a complex financial discussion that is beyond the scope of this research paper, however, it is important to understand the basic impacts of matter on innovation and importantly budgeting (which ultimately impacts research and development through lack of budget). In 2014, Blanchard and Arezki (2014) explored this in context to the industry and innovation stating that whilst low oil prices are great for the global economy overall (lowers cost of transport, manufacturing costs, global transport of goods, lower fuel poverty, etc.). Figure 5 shows oil and gas price in recent history with recent major world events relating to the industry labelled; generally, it can be seen that during times of war or instability of supplies oil price does well, whilst during financial crises such as the

2009 global recession or the 1997 Asian Financial crisis – oil prices fall as spending contracts – these sudden falls are referred to as ‘downturns’. The impact of low oil and gas price on the industry is astounding, with mass layoffs seen in 2014/2015 when there was the most recent industry ‘downturn’ (Datta and Rousset, 2017; Wie, 2015) seeing the lost of predominantly experienced workers (Sumbal et al., 2017). During the global downturn in 2009, Voigt and Moncada-Paternò-Castello (2009), explored the sudden collapse of the oil price and the impacts on innovation, they found that within oil and gas companies and other manufacturing research and development (R&D) funding is the first to be considered for cost-saving measures within companies.

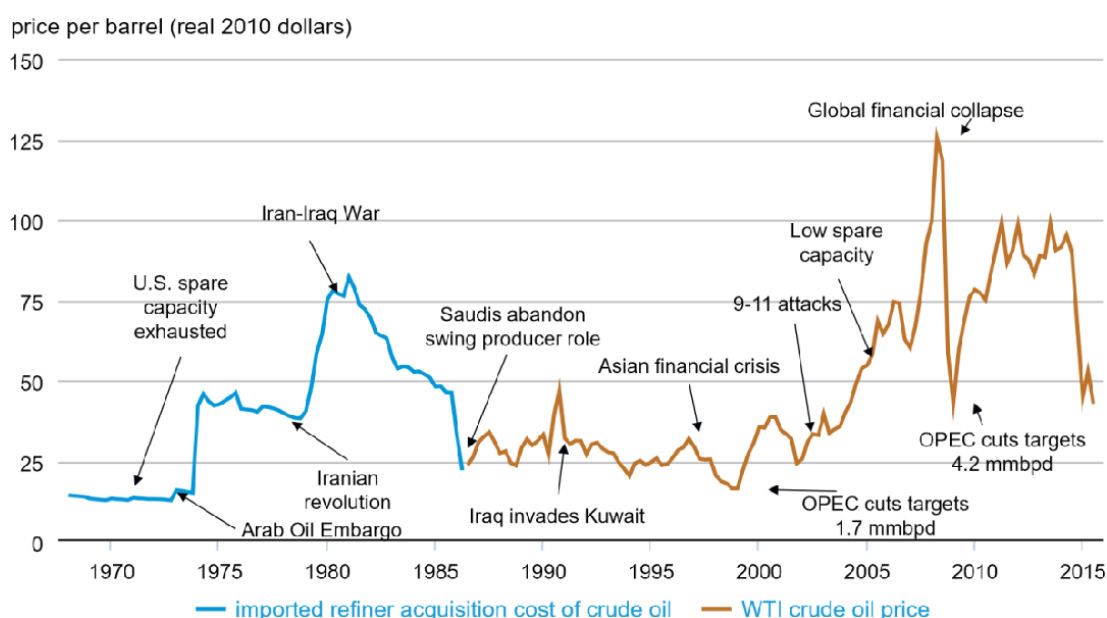


Figure 5- A graph showing the history of the oil price from the late 1960s to 2015 with key world events labelled. (Source: Mert, 2016)

However, other sources dispute this – whilst acknowledging that a general cut in R&D budgets are expected during times of industry/market instability and ultimately lower cashflow, many have referred to the hard times as ‘strengthening’ (Betz, 2015; Gonzales et al., 2018; Kleinberg and Fagan, 2019). Barrett et al. (2009) referred to previous examples where companies during a downturn doubled-down on their R&D and ultimately reaped the rewards when the industry returns to normal after ‘riding out the storm’. This was mainly due to allowing R&D teams time to focus on fee-earning projects, learning new skills (vital to bringing in revenue) and to most importantly renegotiating/rethinking existing R&D projects and

relationships – therefore reducing costs (Barrett et al., 2009). As the most recent downturn took place during the early developments of Industry 4.0 principles (2014/2015) it is hard to evaluate the impact of a future downturn on innovation within the sector currently. With the rise of AI technology starting to spread into widespread use within the industry, the next downturn will be a key turning point unlike downturns experienced in the past, the long-lasting impacts on innovation may be greater than those historically (Lu et al., 2019; Sircar et al., 2021).

3 Literature Review of historic industrial revolutions and their impact on innovation within the Oil and Gas Sector

3.1 Industry 1.0 – The precursor to oil dependence

During the first industrial revolution (~1750 – 1840 (Mohajan, 2019)), there is likely to have been very little impacts by oil and gas contributing to oil and gas being relatively unknown as a resource at this time. Oil was commonly used where oil seeps and peat bogs came to the surface, used locally as roofing sealant for primitive homes and as an antiseptic healing agent for open wounds (Bunce, 2018; Craig et al., 2018). During the first industrial revolution there was an increase in mining, with it being recorded that many mines were ‘leaching’ thick black liquids that would pool in mine workings and shafts. It is here that innovation occurred and sparked the beginning of a wider spread industry. During the mining boom of the early 19th century in Britain, several mines close to naturally occurring hydrocarbon seeps were being impeded by the intrusion of thick oily liquids into mine workings (Craig et al., 2018). It is here that in late 1847 that Dr James ‘Paraffin’ Young was approached by a local mining company in Manchester to deal with their waste problem and to see if any meaningful use could be found for the waste. Using earlier methods developed by other chemists, Young managed to extract a substance he referred to as ‘paraffin’ from the bituminous substance. ‘Paraffin’ lamps had already been invented in the previous 50 years using whale oil, however, paraffin gave access to a quick easy and cheap fuel which brought the invention to the masses (Craig et al., 2018) – this can be considered as one of the earliest uses of

oil and gas in a commercial context. Whilst early oil wells up several hundred feet had been ‘drilled’ by earlier Chinese and Mongolian society (using bamboo methods) (Hassan, 2013), the use of oil and gas during and prior to the first revolution is for that of lighting and medicinal methods. It is only after the development of steam and mechanical technology that commercial oil drilling were possible (Craig et al., 2018; Hassan, 2013).

3.2 Industry 2.0 – Oil burns coal!

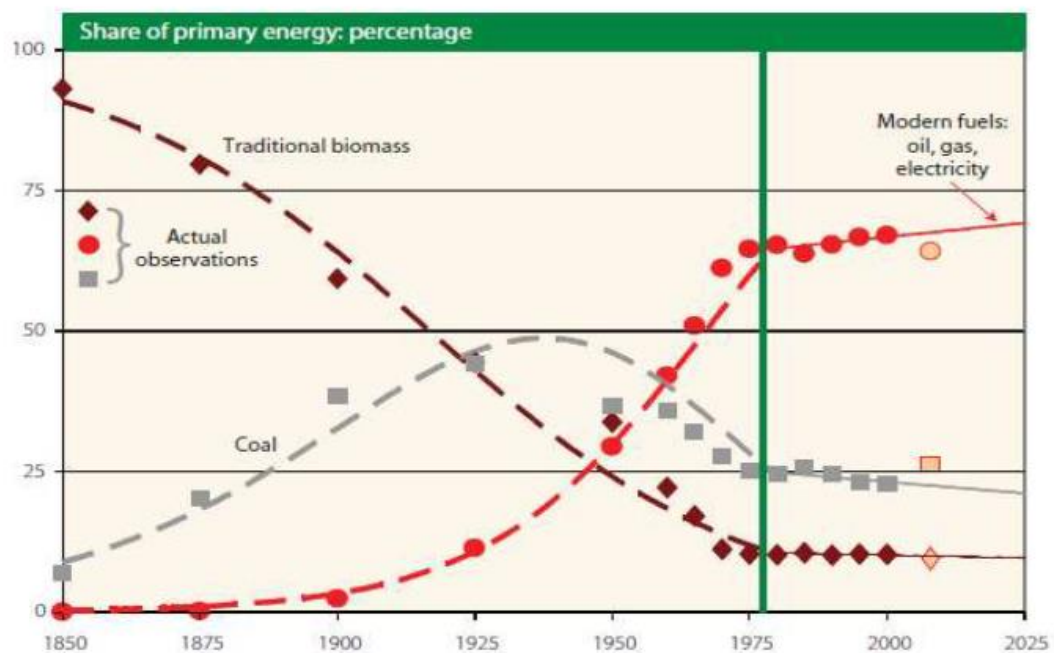


Figure 6 - A graph showing the share of fuels from the end of the first industrial revolution to recent time (Ahuja, 2015)

The second revolution, known as the ‘technological revolution’ followed in 1870 to 1914 (Craig et al., 2018; Jevons, 1931; Mokyr and Strotz, 1998) and this period began to see a key change for the early oil industry. Following the end of the first industrial revolution, coal began to be more readily available and traditional biomass fuels such as wood, peat and charcoal started to decline (see Figure 1). This was due to the invention of the steam engine enabling underground coal deposits to be economically accessed for the first time in human history (Ahuja, 2015). Prior to the rise of coal, all industrial processes were either fuelled by waterwheels close to rivers & waterways or by steam engines fuelled by biomass – however, these had limiting factors. Should waterways dry up in times of drought or forests not regrow

quickly enough, manufacturing areas would stagnate and ultimately decline due to lack of resources. The widespread availability of coal solved these issues and allowed the United Kingdom to become 'the global powerhouse' of the world (Ahuja, 2015; Stearns, 2020). But there was to be another fuel to rise... In the late 19th century the first commercial oil fields had started to rise up in eastern Europe and Asia, with the Baku oilfield being the first to start recording their oil production and export (Craig et al., 2018) – all being made possible by steam engine drilling. With refinery being completed close to production, paraffin type gases were exported for worldwide using in home and street lamps, with consumers being able to buy 'lamp gas' from grocery stores and markets in large cities such as London (Craig et al., 2018). The invention of the internal combustion engine using gasoline, combined with the commercialisation of cracking oil and gas leads to a whole new global avenue for oil and gas (Craig et al., 2018). Whilst the previous industrial revolution hit issues with energy supply early on, the expansion of coal and the advent of oil allowed for continual growth into the 20th century (Stern and Kander, 2012), Stern and Kander (2012) cover this in detail arguing that the previous industrial revolution was harmed in countries that didn't have easy access to such resources. This same barriers still exist today in lesser developed countries (LEDs) such as many African and Asian countries that do not have a well developed electricity grid (Ukwandu, 2018) – this historic problem is seemingly becoming easier to solve however with the ease of access to cheap renewable technology that doesn't require active fuelling that (Barger and Mattson, 2016; Karekezi, 2002; Mapako and Mbewe, 2013). By the end of the second industrial revolution, two key events cemented oil and gas as one of the key energy resources of the world: firstly the change of ship fuels from coal to fuel oil during the First World War (Winegard, 2016) and secondly the invention of the automobile and mass production using the production line by Henry Ford (another second industrial period revolution). After the end of the second world war, the majority of shipping started to switch to oil as it was easier to bunker, whilst the invention of the production line and the first employee reforms and the 'American dream' led to the consumer owning their own vehicle powered by oil and gas (Craig et al., 2018; Jevons, 1931).

3.3 Industry 3.0 – Technological development

The third industrial revolution started in the 1970s and lasted until recent times in the 2000s known as the digital revolution where the world saw the first programmable controllers and digital data entering the manufacturing process for the first time ever (Janicke and Jacob, 2013). Unlike the first and second industrial revolution, the third industrial revolution brought truly global wealth. It is estimated that in the first and second industrial revolution that the vast majority of the development came to Western Europe and North America (specifically the UK and USA), however, by the time of the third revolution, industries had begun to spread globally (Janicke and Jacob, 2013; Mohajan, 2021). Mohajan (2021) examines this in further detail, where his research shows that the third industrial revolution causes approximately 10 times global GDP value growth, when compared to the previous two industrial revolutions. The key changes brought about by the third industrial revolution include: development of programmable electronics, world wide web, computing (including home computing), enhanced robotics, computer aided design and many more! (Janicke and Jacob, 2013). The third industrial revolution began to impact individuals more so than any previous industrial revolution, with access globally to cheaper food and better employment conditions – global life expectancy began to increase globally (Mohajan, 2021). The rapid growth of digital technology has been one of the mainstays of the third industrial revolution, in the late 1980s it was estimated that approximately 1% of all the world's technological data were stored in a digital format, in 2014 that figure has increased to over 99%! (Hilbert and López, 2011), with the home personal computer being one of the key successes from the third industrial revolution. Another difference between the third industrial revolution compared to the previous two aside the immediate digital revolution, is the fact that innovations that were developed during the third industrial revolutions were not made in isolation and improved on. Personal computers were invented in the early revolution, however, the invention of the world wide web opened up an entirely new avenue of opportunity. Computing combined with 'world wide web' technology could connect people globally for the first time without needing to be physically next to another (Troxler, 2013). Despite this the third revolution was not without negatives... Increased reliance on digital technology caused an increase in

electricity required, this globally increasing pollution from increased burning of fossil fuels (such as oil and gas/coal) for electricity (Janicke and Jacob, 2013; Mohajan, 2021).

So, the third industrial revolution had a truly global impact – but what was the impact on the oil and gas industry? Well, it is difficult to quantify and there is very little published on the subject, however, it can be interpreted that the technological revolution seen in the period had a profound impact on the industry. Prior to the 1970s, it was common for most oil and gas prospects to be drilling onshore (on land), with very few drilling activities taking place on bodies of water and often in restricted depths (Howe, 1986). However, advancements in computer processing of seismic logs (a survey technique used to survey layers of rock below the surface) allowed for prospects offshore to be explored economically for the first time (Howe, 1986). Further advances in computer aided design (CAD), coupled with the 3D visualisations enabled by computing have allowed for offshore drilling to become common place in the 21st century, all made possible by digital advances in the 3rd industrial revolution.

4 Industry 4.0 – An old industry in a changing modern world

As mentioned previously, the fourth individual revolution is a recent revolution that mainly surrounds the following technologies: Internet of things (IoT); Industrial Internet of Things (IIoT); smart manufacturing; connected manufacturing; smart factories; cloud computing; cognitive computing; artificial intelligence and cyber-physical systems. All of these technologies together and how they interact with another form the basis for Industry 4.0 (Ślusarczyk, 2018).

As well as these technologies, there is also a focus on Industry 4.0 implementing a 'circular economy' (Rajput and Singh, 2019), which aims to close the gaps between production and consumption – this involves reusing, remanufacturing, repairing etc.: it can be considered as an extension of the reduce, reuse and recycle that dominated the third industrial revolution (Massaro et al., 2021).

Despite being a relatively recent occurrence, Industry 4.0 has already started to have profound effects on the oil and gas industry. Within this chapter the effects of Industry 4.0 on the upstream sector of the oil and gas industry will be examined. The midstream and downstream sectors will not be covered in detail as it is beyond the scope of this study.

4.1 Upstream Sector (Exploration and Production)

The upstream sector of the oil and gas industry is one of the most dynamic, dangerous and rewarding industries on the planet. From the rough swells of the North Sea to the nodding donkey's of the west of Texas – the industry operates in a wide array of environments. From large corporations such as Shell and BP, to a smallholding 'one man bands' in the USA, the industry is one of the most diverse and challenging on the planet. The sector has been previously defined in Section 2.2 as mainly encompassing 'exploration' activities, however, with fossil fuel reserves starting to decline globally and the push towards renewable & sustainable energies increase.

Typically, the upstream sector has been one of the innovative sectors on the planet, with the sector being quick to adopt new and developing technologies: we saw in the first industrial revolution steam engines were adapted to allow for deep drilling; in the second industrial revolution saw wider uses for waste products identified; whilst the third industrial revolution saw the implementation of computer aided technologies being adopted.

The sector faces many challenges, including oil price volatility, high cost, high competition and being a complex and dangerous process (Elijah et al., 2021). So how has Industry 4.0 started to impact or likely to impact the upstream sector to help overcome some of these challenges? This will be discussed below.

The main three activities of the upstream sector are in the following order (see Figure 4): Exploration and Development, Drilling & Well Completion and Production & Production optimisation (Elijah et al., 2021), these activities usually take place in order and may not be fully completed in all areas – some oil may be too expensive to explore therefore a prospect will never be drilled.

Exploration and Development are often started by desk studies of geological structures to explore for areas likely to contain oil and gas. But as technology has developed, companies will adopt and innovate using new technology in order to try to reduce their risk. The average cost of a well drilled offshore costs between \$10,000,000 - \$50,000,000 (as of 2015) (Lukawski et al., 2014), therefore it is imperative that to reduce risk when drilled, and this starts before a well has commenced drilling in the drilling stage.

Seismic is one of the key tools in the oil explorationist toolbox, with geological seismic surveys used extensively to map the surface below ground and identify areas of hydrocarbon 'hotspots'. Traditionally, data were acquired by sensors called geophones (Kent, 1985), that would reflect waves sent by a vibration source (Craig et al., 2018). The resulting data from seismic collection would result a series of 2D planes below the subsurface that can be combined together to create a 3D model of the subsurface. The data is considered 'big data' (Elijah et al., 2021), and gives a host of opportunity for Industry 4.0 technology to be utilised. In 2018 an oil exploration company successfully incorporated principles surrounding the internet of things, utilising the 'big data' generated from seismic and cloud computing to successfully predict the subsurface using machine learning on their seismic surveys (Olneva et al., 2018). Such advancements could allow for initial exploration time to be reduced, thus reducing costs. 4D seismic models were first established in the late 1990s in Norway's Draugen Oilfield, that used multiple 3D seismic models stacked to monitor fluids within an oilfield on the fly (Fanchi et al., 1999). However, despite the technique being successful, it was costly and time consuming so therefore has not been used extensively – mainly due to the large complexity of data and computing power required. However, in recent times with the development of cloud computing and the connected Internet of things – oil companies have successfully applied Industry 4.0 processes to a previously established technology, allowing for quick and easy 'realtime' monitoring of oilfields (Correia et al., 2023). The development of this will be an important tool if carbon sequestration is to be achieved (see Chapter 4.4).

Further use of augmented reality have been combined with the geological data generated from seismic surveys, to allow for a 3D visualisation of the 3D seismic maps produced (Lee et al., 2015; Mathiesen et al., 2012), this allows for better quality control of outputs from interpreted seismic sections (whether it be via traditional human interpretation or machine learning). A secondary, but important use of this – is to train future geoscientists within companies and educational settings (Ababsa et al., 2012; Dluhopolskyi et al., 2019). Geology has traditionally been an industry that has only been fully accessible to mainly able-bodied students and workforce. By incorporating virtual and augmented reality solutions, inclusivity has increased (Dluhopolskyi et al., 2019; Moid, 2020).

Once a prospect has been discovered, a decision will be made to drill or not – and this will depend on a wide range of factors: oil price, complexity of the geology, location, access to refineries etc. Drilling is the main cost in oil and gas exploration and is the most significant investment in a prospect, as previously mentioned costing between \$10-50 million (~£250,000 per day for rig hire) on average for each well drilled offshore. It is therefore important for oil and gas companies to reduce the initial economic risk.

Drilling of prospects only take place after geologists have acquired a certain amount of certainty that oil and gas reserves are in place when drilled (Kellogg, 2014), although some wells may be drilled with a high probability of being dry to either test a scientific theory or a pure shot in the dark referred to as a 'wildcat' (Milkov and Samis, 2020). Due to this, the oil and gas industry has amassed a large amount of collective regional data on wells, often being kept for future use as determined by the country's licensing conditions (Cillari et al., 2021). This means that there is a large data ocean (big data) present with over 40 years of drilling data in some areas that can be used for either supervised training or quality control of machine learning models (Elijah et al., 2021) – such data however would require some sort of cleaning prior to this use. Due to the cost of drilling wells, one of the ways that companies look to reduce the cost is by increasing the ROP ('rate of penetration') of rocks when drilling (Hossain, 2015) – a higher ROP the faster a well is drilled and thus reduces the time required for a rig to be on station. D'Almeida et al. (2022),

discuss how Industry 4.0 is being used to assist drilling, whilst previously drilling data would often be predicted using data from the nearest well to where the drilling is taking place – using the internet of things combined with assisted AI learning, sensors can feed live data to AI models which can be used to predict upcoming changes in ROP and allow for drillers to adjust rig parameters to achieve the best possible ROP (Batruny et al., 2019; Boukredera et al., 2023; D’Almeida et al., 2022). Boukredera et al. (2023) discuss this in depth, with their study discovering that ROP increases by up to 43% when using AI models combined with historic data, leading to a saving in time of between 31 – 64 hours per well. However, it should be noted that models (especially geological models) are fundamentally wrong (Cowan, n.d.; Doveton, 2001) and they shouldn’t be treated as the truth in oil and gas exploration. However, as Doveton (2001) states ‘all models are wrong, but some models are useful’ and in the context of drilling for oil and gas ‘useful’ models can be made for drilling and tested given the abundance of historic data available.

Production is the next phase assuming that oil or gas has been discovered, the drilling rig will be replaced with a production facility and will begin to produce oil and gas. This brings new challenges as the production phase. One such challenge fluids are produced and mixed with drilling leads to the growth of scale within production pipes and pipelines (ultimately reducing the efficiency of production activities). Typically scale prediction is known in areas with fluids that are likely (common in water injection reservoirs), however, prediction mainly involves measuring known scale production over a period of times along pipes (Oddo and Tomson, 1994). However, scale prediction has been enhanced by incorporating this historical data with specialist AI models designed for scale prediction using geochemical parameters – again this integrates past historical data of scale production with modern day sensors (using the internet of things) to live predict scale production (Al-Hajri and AlGhamdi, 2019; Tariq et al., 2021). AI’s are then established to design mitigation techniques to reduce scales during production, usually by adding mixes of additive fluids to the production stream to dissolve scales in situ (Al-Hajri and AlGhamdi, 2019). However, such models have been found by

Tariq et al. (2021) to be individual to specific oilfields, and therefore models must be redesigned for each oil prospect in order to be effective.

Drilling digital twinning is one Industry 4.0 technology that is being used extensively currently in the oil and gas industry, in all areas. Using virtual reality software, models of installations and production plants are being made in order to serve a variety of purposes. Virtual reality can be used on digital twins, towards training staff to the hazards of working on a rig, thus increasing health and safety (Wanasinghe et al., 2020). This is also expanded into simulating a rig environment in order to reduce future retrofitting and that the correct equipment is installed on the launch of the rig/production platform (Havard et al., 2019). Finally, the use of a virtual digital twin can go further, running a real-life simulation concurrently to the drilling rig, the digital twin can be fed real time data in order to predict maintenance schedules. If data differs from the real life to the digital twin, alerts will activate for further investigation. This has been used successfully in a platform where drilling motors in real life were found to be wearing quicker than expected, identifying an issue with the motors and allowing for preventative maintenance, thus avoiding any major downtime and allowing for preventive rather than reactive maintenance to take place (Laborie et al., 2019).

Overall Industry 4.0 technologies are being actively implemented within the industry and are proving to be of value, reducing the cost and time to drill wells and also preventing failure of critical machinery during complex drilling periods.

4.2 Carbon sequestration future –a future Industry 4.0 honeypot?

As the circular economy is one of the key cornerstone principles behind Industry 4.0 (Rajput and Singh, 2019), you would be excused from thinking that the oil and gas industry is not compatible with Industry 4.0 at all. After all, oil and gas is a carry over from the second industrial period, coal – saw a decline, so why not oil and gas?

The simple fact is that the demand for oil and gas is still increasing, and as stated in an earlier chapter it is still an important resource – therefore the industry is still growing. There is also another future development that is arguably an Industry 4.0

development: carbon sequestration. Carbon sequestration describes the deep long term storage of carbon dioxide and other associated greenhouse gases. As the oil and gas industry is expected to be one of the largest contributors to the carbon sequestration sector, it is vital that knowledge gained from implementing Industry 4.0 to oil and gas exploration, is utilised in applying similar methods to the carbon sequestration sector (Elijah et al., 2021).

Table 2. Summary of Likert results from respondents by department. 1A – overall results. 1B – administration department. 1C – biostratigraphy departments. 1D – laboratory department. 1E – New Ventures department. 1F – reservoir geology department. Note the total respondents for each department and modal categories are given to the right of each table.

Table 1A. - Overall results							
Statement	Strongly Disagree	Disagree	Agree or Disagree	Agree	Strongly Agree	Total	Modal Category
Changes that occur from industrial revolutions are necessary to advance society	0	5	3	26	11	45	Agree
Advancements in automation pose a risk to jobs OVERALL	2	13	7	17	6	45	Agree
Advancements in automation pose a risk to MY JOB	4	25	8	8	0	45	Disagree
Businesses will use Industry 4.0 technology to reduce headcounts	0	4	17	21	3	45	Agree
I am willing to learn new skills to ease the transition into an Industry 4.0 workplace	0	1	6	18	20	45	Strongly Agree
I will try to avoid using Industry 4.0 technology in the workplace	12	17	14	1	1	45	Disagree
Table 1B. - Admin Department							
Statement	Strongly Disagree	Disagree	Agree or Disagree	Agree	Strongly Agree	Total	Modal Category
Changes that occur from industrial revolutions are necessary to advance society	0	1	0	6	3	10	Agree
Advancements in automation pose a risk to jobs OVERALL	1	7	1	1	0	10	Disagree
Advancements in automation pose a risk to MY JOB	3	7	0	0	0	10	Disagree
Businesses will use Industry 4.0 technology to reduce headcounts	0	1	5	4	0	10	Neither agree or disagree
I am willing to learn new skills to ease the transition into an Industry 4.0 workplace	0	0	0	6	4	10	Agree
I will try to avoid using Industry 4.0 technology in the workplace	2	6	2	0	0	10	Disagree
Table 1C.- Biostratigraphy Department							
Statement	Strongly Disagree	Disagree	Agree or Disagree	Agree	Strongly Agree	Total	Modal Category
Changes that occur from industrial revolutions are necessary to advance society	0	1	1	11	1	14	Agree
Advancements in automation pose a risk to jobs OVERALL	0	3	1	7	3	14	Agree
Advancements in automation pose a risk to MY JOB	0	7	3	4	0	14	Disagree
Businesses will use Industry 4.0 technology to reduce headcounts	0	1	6	6	1	14	Neither agree or disagree/Agree
I am willing to learn new skills to ease the transition into an Industry 4.0 workplace	0	0	2	6	6	14	Agree/Strongly Agree
I will try to avoid using Industry 4.0 technology in the workplace	3	5	6	0	0	14	Neither agree or disagree
Table 1D. - Laboratory Department							
Statement	Strongly Disagree	Disagree	Agree or Disagree	Agree	Strongly Agree	Total	Modal Category
Changes that occur from industrial revolutions are necessary to advance society	0	0	1	4	1	6	Agree
Advancements in automation pose a risk to jobs OVERALL	0	0	3	3	0	6	Neither agree or disagree/Agree
Advancements in automation pose a risk to MY JOB	0	3	3	0	0	6	Neither agree or disagree/Disagree
Businesses will use Industry 4.0 technology to reduce headcounts	0	0	3	3	0	6	Neither agree or disagree/Agree
I am willing to learn new skills to ease the transition into an Industry 4.0 workplace	0	0	1	4	1	6	Agree
I will try to avoid using Industry 4.0 technology in the workplace	0	2	3	0	1	6	Neither agree or disagree
Table 1E. - New Ventures Department							
Statement	Strongly Disagree	Disagree	Agree or Disagree	Agree	Strongly Agree	Total	Modal Category
Changes that occur from industrial revolutions are necessary to advance society	0	0	0	2	3	5	Strongly agree
Advancements in automation pose a risk to jobs OVERALL	1	0	1	2	1	5	Agree
Advancements in automation pose a risk to MY JOB	1	3	1	0	0	5	Disagree
Businesses will use Industry 4.0 technology to reduce headcounts	0	2	0	2	1	5	Disagree/Agree
I am willing to learn new skills to ease the transition into an Industry 4.0 workplace	0	0	0	1	4	5	Strongly agree
I will try to avoid using Industry 4.0 technology in the workplace	3	1	1	0	0	5	Strongly disagree
Table 1F.- Reservoir Geology Department							
Statement	Strongly Disagree	Disagree	Agree or Disagree	Agree	Strongly Agree	Total	Modal Category
Changes that occur from industrial revolutions are necessary to advance society	0	4	0	3	3	10	Disagree
Advancements in automation pose a risk to jobs OVERALL	0	3	1	4	2	10	Agree
Advancements in automation pose a risk to MY JOB	0	5	1	4	0	10	Disagree
Businesses will use Industry 4.0 technology to reduce headcounts	0	0	3	6	1	10	Agree
I am willing to learn new skills to ease the transition into an Industry 4.0 workplace	0	1	3	1	5	10	Strongly agree
I will try to avoid using Industry 4.0 technology in the workplace	4	3	2	1	0	10	Strongly disagree

5 Industry 4.0 perceptions within an upstream SME consultancy

This chapter will review the attitudes towards automation and adoption of Industry 4.0 technology and processes. The survey can be viewed in Enclosure 1 (Appendices), and is designed around a Likert questionnaire to gauge the views of the several departments present within PetroStrat (which will be explained in Section 5.1). Enclosure 2 (Appendices) shows all responses tabulated. Table 2 shows the summary of Likert responses tabulated per department within PetroStrat.

A total of 45 respondents were received from employees within PetroStrat – prior permission for the survey was verbally given by management with the condition that results were not published without permission of the PetroStrat Directors (see Notice of Non-Publication after the Acknowledgements section). The survey was given anonymous and delivered to staff via an internal memo using Microsoft Forms. A full declaration on the use of data and the right to withdraw was given as part of the survey introduction and can be viewed in Enclosure 1, a choice was also given to respondents for if they wanted to enter into a prize draw for a chance to win a Toblerone to fill out the survey (a total of 34 respondents chose to enter this draw).

Within the form, the following background information was given:

“Evaluating perceptions of Industry 4.0+ technologies with employees

Research Background:

Industry 4.0 is the term given to the latest industrial revolution. In recent human history there have been four industrial revolutions.

Industry 4.0 takes advances in automation and digitalisation that were made in the third industrial revolution, with the aim of increasing operational efficiency of companies. Unlike previous industrial revolutions, part of the Industry 4.0 philosophy aims to close the loop between business operations & environmental impacts by creating/implementing circular economy workflows.

Whilst it will be impossible until long into the future to evaluate the effectiveness of Industry 4.0 implementation, this survey aims to evaluate the current perception and feeling towards Industry 4.0 technology from employees specifically from oil and gas service companies.

Further background information about Industry 4.0 can be found at the following links:

<https://www.ibm.com/topics/industry-4-0>

<https://www.forbes.com/sites/bernardmarr/2018/09/02/what-is-industry-4-0-heres-a-super-easy-explanation-for-anyone/?sh=478d13ee9788>

The basic background given to employees so that if they have no prior knowledge of Industry 4.0 technology that they have a chance to research the principles and processes behind this (although it is not necessary as this survey aims to establish **current** perceptions of Industry 4.0 technologies and processes without any prejudice). Of the 45 respondents, a total of 11 respondents had a knowledge of Industry 4.0 technology but in the most part this is the first time that respondents had been introduced to Industry 4.0.

The survey aims to identify the perceptions from employees within PetroStrat towards the following statements:

- 1) Changes that occur from industrial revolutions are necessary to advance society
- 2) Advancements in automation pose a risk to jobs OVERALL
- 3) Advancements in automation pose a risk to MY JOB
- 4) Businesses will use Industry 4.0 technology to reduce headcounts
- 5) I am willing to learn new skills to ease the transition into an Industry 4.0 workplace
- 6) I will try to avoid using Industry 4.0 technology in the workplace

The statements are designed to be linked to another in order to reduce anomalous data, although statistics show that the average time for completion is at 4 minutes which is above the author's benchmarked test expected time of 2-3 minutes, meaning that the majority of respondents have considered their responses and the data is likely to be valid. If this survey were to be repeated in the future, a higher sample count could mean that further statistical analysis could be performed to eliminate any potential anomalous results or outliers, but this is beyond the scope

of this study and would require wider industry involvement. As Likert data is classified as 'ordinal data' (Allen and Seaman, 2007; Batterton and Hale, 2017), no statistical analysis has been performed on the dataset, although statistical analysis such as mean and standard deviations of responses can be performed (Sullivan and Artino Jr, 2013). Due to the limited responses within the study and the ambiguity of analysing ordinal data combined together, the author has therefore chosen not to perform any statistical analysis, however, this could form the basis of future studies.

5.1 Background to PetroStrat

PetroStrat Ltd is a geological consultancy based in North Wales, with offices in England, USA and Canada that provides specialist geological analysis to companies predominantly in the oil and gas industry, although, work for other industries within the energy/resource sectors is not uncommon (e.g. geothermal, carbon storage and hydrogeology analysis).

The company has just over 100 employees and was founded back in the early 2000s, gradually growing and expanding to its current size through a series of organic growth spurts and shrewd acquisitions of competitors operating in the same industry areas. PetroStrat assists companies in both the exploration and drilling stages; collecting, analysing and interpreting geological data from samples.

The company can be summarised as having five major departments: Administration (Admin); Biostratigraphy; Laboratories; New Ventures; Reservoir Geology.

Administration and Management department comprises human resources (HR), administrative, management and ancillary staff (such as Operations, IT and Continuous Improvement Management). The department handles all admin and logistics for the company, as well as financial reporting.

Biostratigraphy department is composed of Nanopalaeontology, Micro palaeontology and Palynology departments. The departments study the distribution of fossil assemblages in rocks in order to correlate between units and provide time

markers in geological samples between wells. They operate both in the office environment and offshore on rig installations.

Laboratory department comprises laboratory staff that work across PetroStrat's several locations across Wales, England and the United States. The laboratories prepare samples for scientific departments (Biostratigraphy and Reservoir Geology) from clients for analysis. They operate both in the office environment and offshore on rig installations.

New Ventures department are the department within PetroStrat that are responsible for developing new work processes and methodologies. They work alongside other departments to progress and facilitate research and development ideas.

Reservoir geology department is the department that studies the 'reservoir quality' and sedimentology of oil and gas reservoirs, creating paleogeographic models used for interpreting rock units between wells. They operate both in the office environment and offshore on rig installations.

5.2 Perceptions towards IR4 within PetroStrat

5.2.1 Results of the survey

5.2.1.1 All departments combined

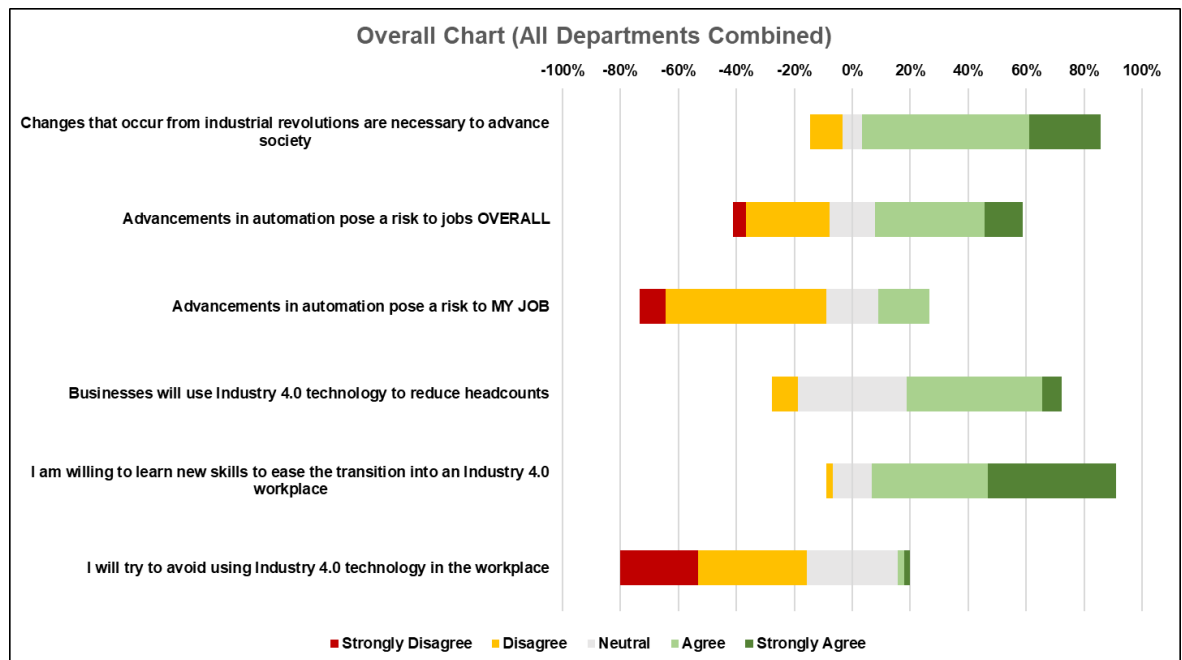


Figure 7 - A Likert summary chart for all departments combined. A total of 45 respondents were recorded overall.

Responses from all departments combined are shown in Figure 7. The findings of the study showed that in general PetroStrat employees believe that industrial revolutions are necessary to advance society, although some disagree.

Automation has a mixed response however, with respondents generally split on the risks automation has to jobs overall, although the majority agree that automation will pose a risk to jobs in the future. However, the opposite is true to employees perception about their own job, with the majority disagreeing that automation poses a risk to their job. Overall PetroStrat employees agree that businesses will use Industry 4.0 to reduce headcount.

Training and development shows that the majority of staff overall within PetroStrat are willing to learn new skills to transition into an Industry 4.0 workplace, although there is a minority are unwilling to do so – examining the data these datapoints are in the 65+ category and are likely close to retirement.

5.2.1.2 Admin and Management Department

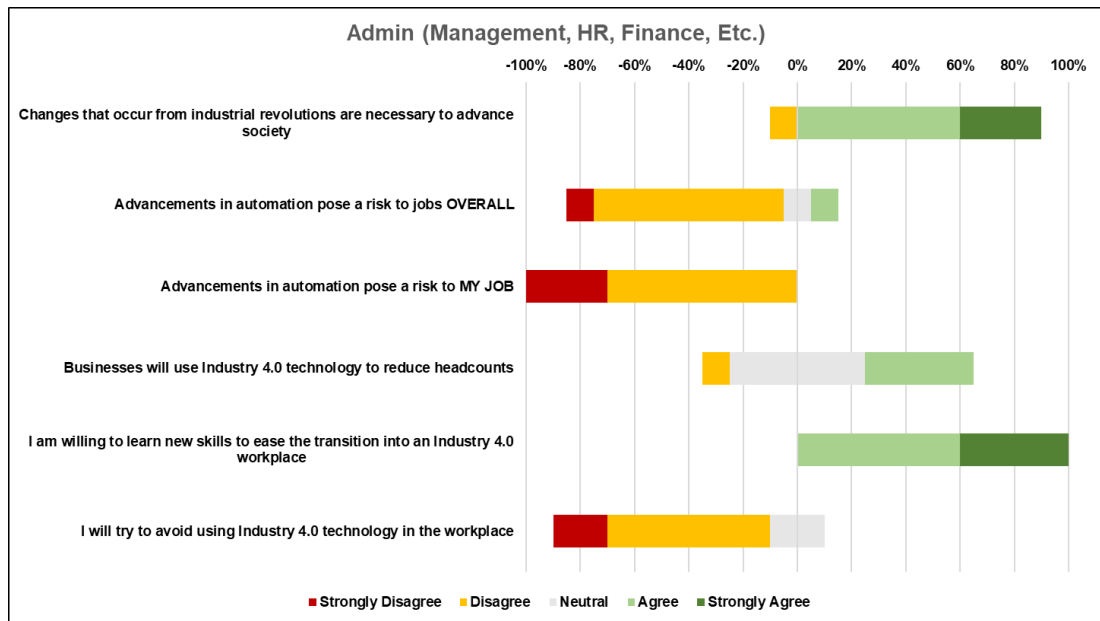


Figure 8 - A Likert summary chart for the administration department. A total of 10 respondents were recorded for the administration department.

Responses from the administration department are shown in Figure 8. The findings of the study showed that in general PetroStrat employees believe that industrial revolutions are necessary to advance society, although some disagree.

Automation has a collection responsive, with respondents generally against the statement that automation will pose a risk to both jobs overall and their job. However, administration employees agree that businesses will use Industry 4.0 to reduce headcounts across businesses.

Training and development shows that the majority of staff overall within PetroStrat are willing to learn new skills to transition into an Industry 4.0 workplace and will not avoid using any associated technology.

5.2.1.3 Biostratigraphy Department

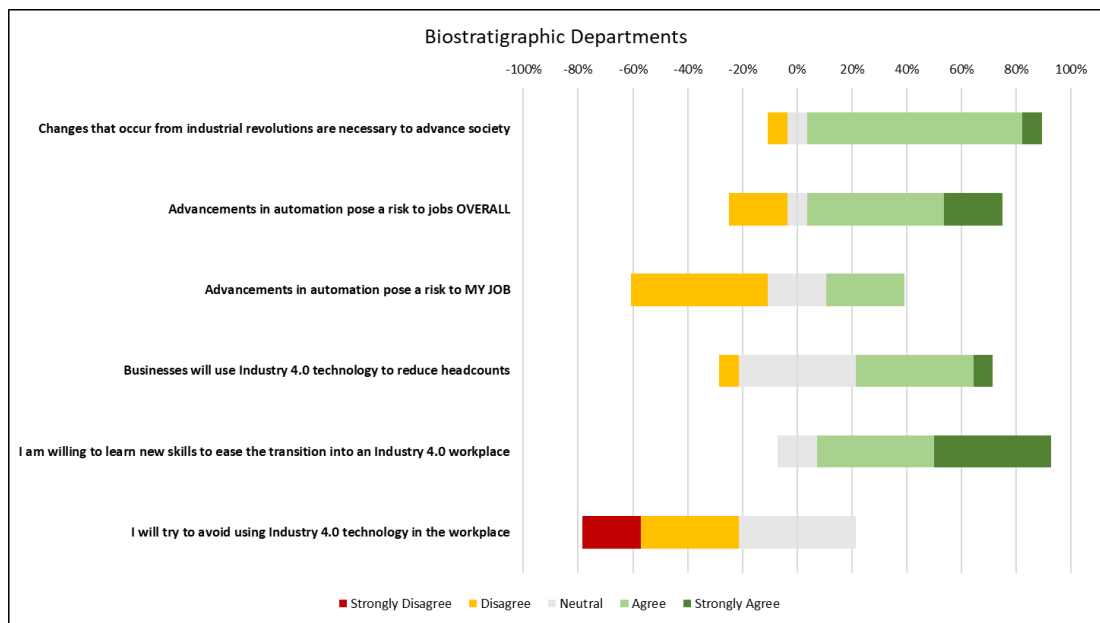


Figure 9 - A Likert summary chart for the biostratigraphy department. A total of 14 respondents were recorded for the biostratigraphy department.

Responses from the biostratigraphy departments are shown in Figure 9. The findings of the study showed that in general biostratigraphy department employees believe that industrial revolutions are necessary to advance society, although some disagree.

Automation has a mixed response however, with respondents generally split on the risks automation has to jobs overall, although the majority agree that automation will pose a risk to jobs in the future. Meanwhile, there is a lack of consensus that automation poses a risk to their job. Overall biostratigraphy department employees agree that businesses will use Industry 4.0 to reduce headcount

Training and development shows that the majority of staff overall within PetroStrat are willing to learn new skills to transition into an Industry 4.0 workplace and will not avoid using any associated technology.

5.2.1.4 Laboratory Department

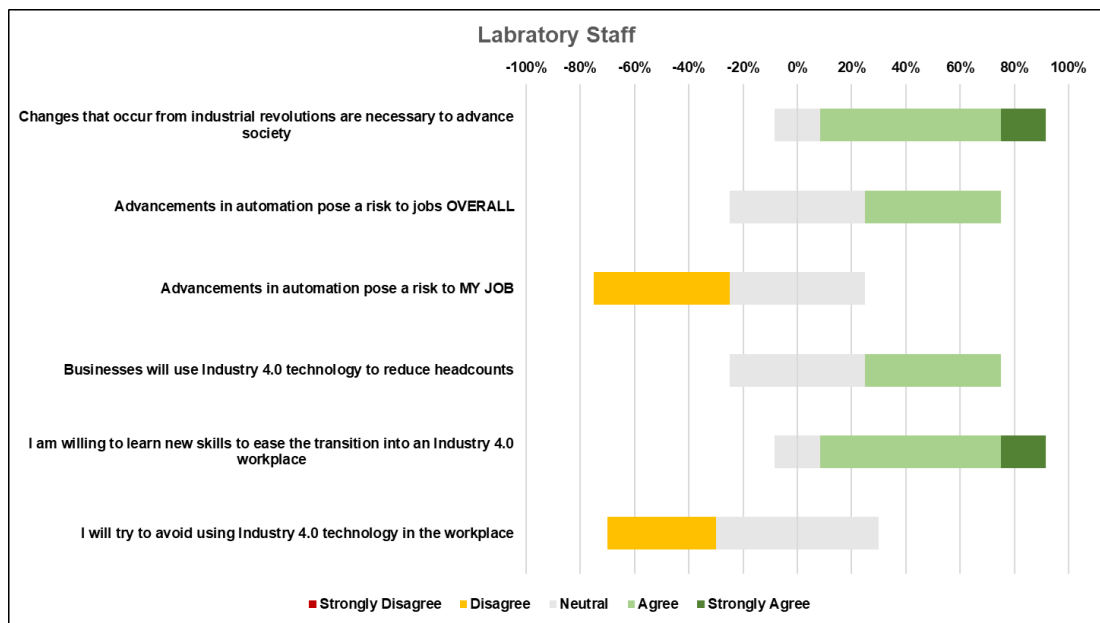


Figure 10 - A Likert summary chart for the laboratory department. A total of 6 respondents were recorded for the laboratory department.

Responses from the laboratory department are shown in Figure 10. The findings of the study showed that laboratory department employees believe that industrial revolutions are necessary to advance society.

Automation has a mixed response however, with respondents generally split on the risks automation has to jobs overall, although they tend to agree that automation will pose a risk to jobs in the future. Meanwhile, there is a lack of consensus that automation poses a risk to their job and the risk to jobs overall.

Training and development shows that the majority of staff overall within PetroStrat are willing to learn new skills to transition into an Industry 4.0 workplace, however, the majority will neither agree or disagree to avoiding using Industry 4.0 technology in the workplace.

5.2.1.5 New Ventures Department

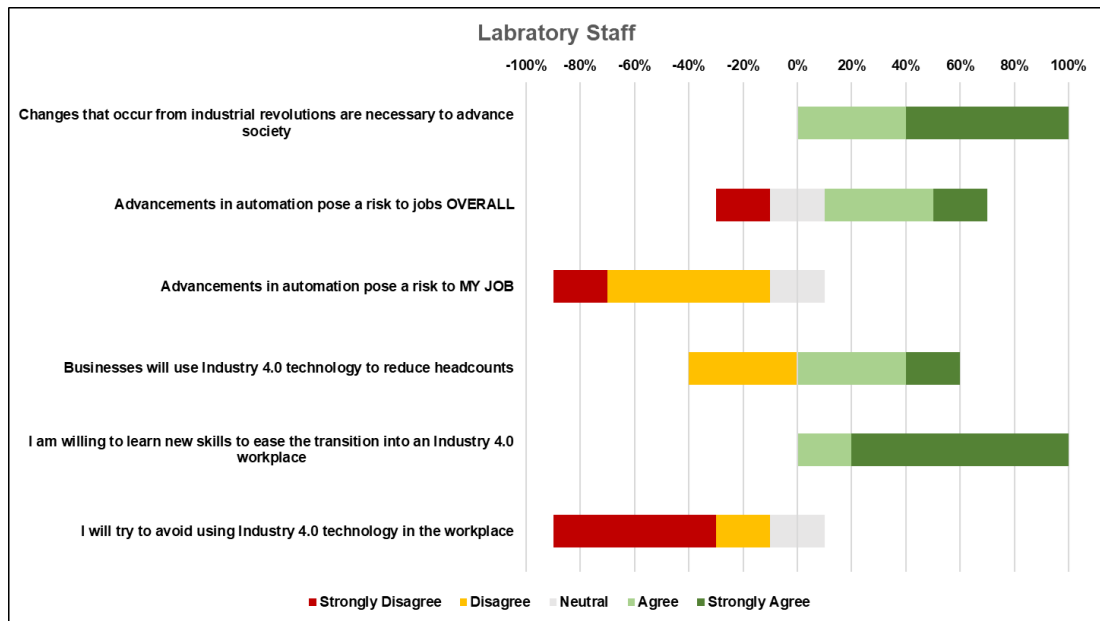


Figure 11 - A Likert summary chart for the new ventures department. A total of 5 respondents were recorded for the new ventures department.

Responses from the new ventures department are shown in Figure 11. The findings of the study showed that in general new ventures employees believe that industrial revolutions are necessary to advance society.

Automation has a collection responsive, with respondents generally against the statement that automation will pose a risk to both jobs overall, although some disagree. Meanwhile, new ventures staff members do not believe that automation poses a risk to their job. New ventures staff members are split as to whether businesses will use Industry 4.0 technology to reduce headcounts, although there is a slight leaning towards agreement that IR4 technology will lead businesses to reduce headcounts.

Training and development shows that all new ventures staff are willing to learn new skills to transition into an Industry 4.0 workplace and will also not try avoid using any associated technology.

5.2.1.6 Reservoir Geology Department

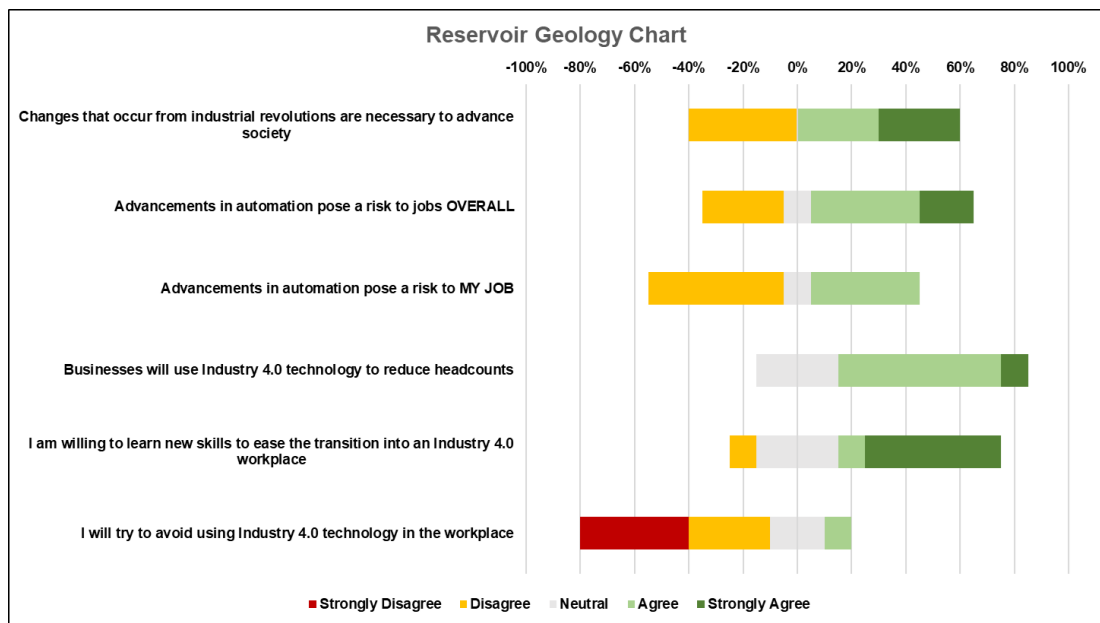


Figure 12 - A Likert summary chart for the reservoir geology department. A total of 10 respondents were recorded for the reservoir department.

Responses from the new ventures department are shown in Figure 12. The findings of the study showed that in general reservoir geology employees believe that industrial revolutions are necessary to advance society, although some disagree.

Automation has a collection responsive, with respondents generally agreeing with the statement that automation will pose a risk to both jobs overall, although some disagree. Meanwhile, new ventures staff members do not believe that automation poses a risk to their job. Reservoir geology respondents believe that businesses will use Industry 4.0 technology to reduce headcounts.

Training and development shows that the majority of staff overall within the reservoir geology department are willing to learn new skills to transition into an Industry 4.0 workplace, although there is a minority are unwilling to do so – examining the data these datapoints are in the 65+ category and are likely close to retirement. The majority of respondents will not try to avoid using Industry 4.0 technology, although, some do agree they will – again this is likely to be a staff member close to retirement.

5.3 Survey Summary and Conclusions

The full results of the survey broken down for each department are viewable in Figures 7 – 12, in general the responses of all employees and departments are broadly consistent (see Figure 7) to the statements provided in the survey. The employees that responded to the survey generally were in favour of automation and Industry 4.0 technology within the workplace. They also agreed that there was willing to train and develop their skills to ease a transition into a future Industry 4.0 workplace. However, there is some concern amongst employees that Industry 4.0 technology and processes, as well as advancements in automation will pose a risk to jobs overall (in other businesses).

Very few studies have been performed on the perceptions of Industry 4.0 overall, and within oil and gas there are no known literature (searched via Google Scholar and Web of Science) that have explored this topic. However, there have been some studies in other industries that have explored this. Soukupová et al. (2020) explored employee perceptions of Industry 4.0 technology and processes within large enterprises within the Czech Republic, the study found that there was a general hesitance by employees due to fears that Industry 4.0 would ‘eliminate’ or at best change their job. Müller (2019) explored this in further detail, exploring employee perceptions within a large production plant facility. The study found that there was a low acceptance rate towards Industry 4.0 technology and that reasons given were due to: “fear of job losses; lacking experience with new technologies; older employees believing their competencies are insufficient leading to redundancy and fear of the unknown”. As this study has found that the employee perceptions are generally positive within PetroStrat towards Industry 4.0 this shouldn’t be an issue, however, the fear of any potential job will need to be allayed as there is some unease by some employees towards Industry 4.0 and associated automation of processes.

There is also a clear lack of knowledge/awareness of Industry 4.0 within PetroStrat, which has been identified as a key barrier by Sharma et al. (2023) to IR4 adoption. It is suggested that the company would benefit from wider awareness/education on the potential benefits from Industry 4.0 to the company.

6 Barriers to Industry 4.0 adoption within the oil and gas industry

There is no doubt that implemented correctly into existing workflows, Industry 4.0 can add significant value to businesses that choose to implement such workflows (Telukdarie et al., 2018). However, there are many barriers to such implementation that have been identified by several researchers since Industry 4.0 came to be, these can be summarised as:

- **High implementation costs** – the initial investment is quite variable depending on the processes and company already in place. Companies can be put off investing in Industry 4.0 as sometimes the initial financial benefits cannot be seen (Kumar et al., 2021).
- **Lack of standardisation of device protocols** – this means that newer technologies such as the Internet of Things is difficult to implement on older technology that hasn't considered future connections in their initial design (Burns et al., 2019). This has been overcome by some companies by using live image analysis software of old Analog gauges to feed data into their digital models and to use augmented reality for data visualisation in monitoring processes etc (Althobaiti et al., 2021). However, many systems will not have the ability to be integrated into Industry 4.0 practices so would require replacement.
- **Infrastructure/Country development level** - Similar to the previous point, some companies (or countries) may lack the necessary infrastructure to implement industry 4.0 technologies (Kumar et al., 2021). Whilst high-speed internet is becoming more widely available, in some areas/countries it is difficult to maintain and may prove to be a barrier to IR4 deployment. This is more likely to be a problem in less economically developed countries.
- **Cybersecurity** – many companies are unwilling to open and connect data internally, due to the fear that data will be accessible to the public or leaked in any type of cyber attack (Stentoft et al., 2021). This is likely to be a problem for smaller companies that do not have the expertise/knowledge of cyber security, nor can afford a large cybersecurity team to test and ensure data is secure (Arroyabe et al., 2024).
- **Company culture** – As Industry 4.0 sometimes requires novel thinking for implementation with older software and processes, there can be resistance from staff that do not understand the benefits (Horváth and Szabó, 2019). Similarly if a company has a poor or toxic culture surrounding innovation/R&D, it is likely to prove a key stumbling block to Industry 4.0 implementation (Orzes et al., 2018). A thorough knowledge of existing processes are key, and if staff gatekeep key

information to prevent implementation – it may prove counter intuitive to attempt to adopt Industry 4.0 methods. Similarly, companies that are not used to evaluating their ability to implement technology (e.g. using NASA's technology readiness level) may be unaware of the wider implications on their business.

- **Workforce/human resources** - Similarly there is a current lack of skilled workers (specifically 'Industry 4.0' expert engineers) who would be the ones to facilitate implementation (Horváth and Szabó, 2019; Raj et al., 2020). Similarly as Industry 4.0 is recent, recruitment teams and human resources in charge of hiring may not understand the importance of IR4 skilled workers or even how to identify them. This could lead to hires that do not fit the direction a company is wanting to travel towards in Industry 4.0 implementation.
- **Lack of company awareness** – this is very similar to company culture, however, if nobody within a company (ranging from the cleaner to the MD) are aware of Industry 4.0, then they will never understand the importance of it. This is why education and increased awareness of Industry 4.0 practices is important in Industry settings (Horváth and Szabó, 2019).
- **Regulatory compliance** – is a challenge to most companies on a normal operating basis, however, it is more of a challenge trying to remain compliant to regulatory requirements that are older and not designed with Industry 4.0 implementation in mind (Chauhan et al., 2021; Gromova et al., 2022). This represents a significant barrier and opens up a whole new discussion around whether regulation is a necessary safeguard against reckless implementation or a barrier to process improvement.

Despite the above often being referred to as generic barriers of Industry 4.0, all of these barriers are likely to exist in the oil and gas industry. A recent paper by Sharma et al. (2023) explores this in detail in regard to implementing circular economy principles into the oil and gas industry and the reasoning why companies have not been quicker to adopt such practices – as the circular economy is a key Industry 4.0 principles lessons can be learned from their research into wider Industry 4.0 technology. Whilst (Sharma et al., 2023) did identify the same 8 barriers above that effect other industries too, Sharma found that infrastructure challenges (such as financial, implementation/infrastructure, etc.) can be overcome with enough thought, however, without the knowledge and understanding of Industry 4.0 within a company – companies/employees will never understand the benefit of Industry 4.0 adoption in the first place. Technical/regulatory barriers have

always been there and can be overcome, but, if you are unaware that there is a better way then you will continue how you've always been doing it.

The solution to barriers to Industry 4.0 lies in a simple thing, education (Mian et al., 2020). If companies are able to educate their staff, then ways around will be developed to overcome the other challenges mentioned previously. Similarly, education has been identified as one of the findings required for the company (Petrostrat) in this study, with 34 respondents to the survey (out of 45 total) indicating that they'd never heard of Industry 4.0.

It is therefore key as we move forward into an Industry 4.0 workplace that companies don't invest first in implementing IR4 processes, but instead invest money in educating their employees and key stakeholders on the benefits & possibilities of IR4 adoption. The findings of this study lead the author to recommend that key stakeholders and policymakers should look to incorporate Industry 4.0 within standard university teachings so there is a wider knowledge outside that of specialist courses.

As Malcom X once said, *"Education is the passport to the future, for tomorrow belongs to those who prepare for it today."*

7 Conclusions

- The historical impacts of previous Industrial Revolutions have had a huge impact on the oil and gas industry, with each industrial revolution allowing for expansion and new technology to be brought into use and ultimately increase the efficiency of drilling for oil and gas. As well as this new uses for oil and gas have been developed within different industries as a result from oil and gas (e.g. paraffin lamps from mining waste in the first industrial revolution).
- Current developments in the oil and gas industry using Industry 4.0 technology are vast and changes depending on the sector of the industry. Within drilling and exploration for example, AR/VR technology has been utilised to create models/digital twins of oil rigs, whilst big data analytics is giving new life to old historic data. Industry 4.0 technology and processes are actively being used in the oil and gas industry to increase efficiency and reduce costs.
- Opportunities for Industry 4.0 technologies are being explored constantly, with carbon sequestration potentially giving a whole new industry outlet for IR4 technology to be applied to.
- This study has found that the employee perceptions are generally positive within PetroStrat towards Industry 4.0. The majority of employees show that they are positive towards learning new skills to ease themselves into an Industry 4.0 era within PetroStrat. There are some concerns regarding the potential for Industry 4.0 and automation processes to reduce headcounts overall, although, this is not the opinion towards employees within PetroStrat regarding their current role. It is suggested that management within PetroStrat should consider wider awareness training to ensure staff are aware of the possibilities of IR4 adoption, and to alleviate any concerns that staff may have regarding any potential job security.
- Education and lack of awareness were found to be the main two barriers to Industry 4.0 adoption within the industry. Although more barriers do exist, these can be overcome with technical or political solutions, however, a background knowledge in Industry 4.0 is required for employees and companies to overcome these challenges.

8 Recommendations

- Recommendations from this study are to consider surveying the wider industry sectors to compare the results to this study and allow for statistical analysis of the data. Future studies should also examine the midstream and downstream sectors of oil and gas, and identify if there are any crossover opportunities for IR4 technology.
- Further recommendation is given to PetroStrat management on the importance of educating staff members on what Industry 4.0 is and what it could mean in terms of process development in order to increase the likelihood of acceptance amongst employees. This is especially important as 34 respondents to the study had never heard of Industry 4.0 prior to the survey being conducted for this study.
- Political and educational policymakers should explore the possibility of incorporating Industry 4.0 into current educational pathways across various industries so that there is a wider knowledge of Industry 4.0 technology and processes outside that of specialist engineers.

9 References

- Ababsa, F., Zendjebil, I., Didier, J.-Y., Pouderoux, J., Vairon, J., 2012. Outdoor augmented reality system for geological applications, in: 2012 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM). IEEE, pp. 416–421.
- Ahuja, E., 2015. Energy Change-Insights from the 1st and 2nd Industrial Revolutions and Recent Developments to help achieve the next Low Carbon Industrial Revolution.
- Al-Hajri, N.M., AlGhamdi, A., 2019. Scale Prediction and Inhibition Design Using Machine Learning Techniques, in: SPE Gas & Oil Technology Showcase and Conference. SPE, p. D021S007R003.
- Allen, I.E., Seaman, C.A., 2007. Likert scales and data analyses. Qual. Prog. 40, 64–65.
- Alpaydin, E., 2021. Machine learning. Mit Press.
- Althobaiti, A., Abdellatif, F., Alrasheed, A., Trigui, H., Alsaadi, A., Patel, S., 2021. AR Gauge Scanner Mobile Application, in: Abu Dhabi International Petroleum Exhibition and Conference. SPE, p. D031S099R001.
- Alur, R., 2015. Principles of cyber-physical systems. MIT press.
- Arroyabe, M.F., Arranz, C.F.A., de Arroyabe, I.F., de Arroyabe, J.C.F., 2024. The effect of IT security issues on the implementation of industry 4.0 in SMEs: Barriers and challenges. Technol. Forecast. Soc. Change 199, 123051.
- Bai, C., Dallasega, P., Orzes, G., Sarkis, J., 2020. Industry 4.0 technologies assessment: A sustainability perspective. Int. J. Prod. Econ. 229, 107776.
- Bai, C., Kusi-Sarpong, S., Sarkis, J., 2017. An implementation path for green information technology systems in the Ghanaian mining industry. J. Clean. Prod. 164, 1105–1123.
- Barger, K.M., Mattson, C.A., 2016. Renewable Energy Needs in Developing

Countries: Barriers That Can Be Solved With Engineering, in: ASME International Mechanical Engineering Congress and Exposition. American Society of Mechanical Engineers, p. V005T06A025.

Barrett, C.W., Musso, C.S., Padhi, A., 2009. Upgrading R&D in a downturn. McKinsey Q. 2, 1–3.

Barua, A., 2013. Methods for decision-making in survey questionnaires based on Likert scale. J. asian Sci. Res. 3, 35–38.

Batruny, P., Yahya, H., Kadir, N., Omar, A., Zakaria, Z., Batamale, S., Jayah, N., 2019. Drilling in the digital age: an approach to optimizing ROP using machine learning, in: Abu Dhabi International Petroleum Exhibition and Conference. SPE, p. D031S096R004.

Batterton, K.A., Hale, K.N., 2017. The Likert scale what it is and how to use it. Phalanx 50, 32–39.

Berners-Lee, M., Clark, D., 2013. The Burning Question: We can't burn half the world's oil, coal and gas. So how do we quit? Profile Books.

Betz, J., 2015. University Research and Development Steady in Industry Downturn. J. Pet. Technol. 67, 56–58.

Birkel, H.S., Veile, J.W., Müller, J.M., Hartmann, E., Voigt, K.-I., 2019. Development of a risk framework for Industry 4.0 in the context of sustainability for established manufacturers. Sustainability 11, 384.

Blanchard, O., Arezki, R., 2014. Seven Questions About The Recent Oil Price Slump [WWW Document]. Int. Monet. Fund. URL <https://www.imf.org/en/Blogs/Articles/2014/12/22/seven-questions-about-the-recent-oil-price-slump>

Boukredera, F.S., Youcefi, M.R., Hadjadj, A., Ezenkwu, C.P., Vaziri, V., Aphale, S.S., 2023. Enhancing the drilling efficiency through the application of machine learning and optimization algorithm. Eng. Appl. Artif. Intell. 126, 107035.

British Plastics Federation, 2024. How will plastics be affected by dwindling oil

reserves? [WWW Document]. bpf.co.uk. URL
https://www.bpf.co.uk/press/Oil_Consumption.aspx

Bunce, J., 2018. The history of exploration and development of the Liverpool Bay fields and the East Irish Sea Basin. *Geol. Soc. Spec. Publ.* 465, 95–118 Jonathan Craig, Francesco Gerali, Fiona Macaulay, Rasoul Sorkhabi.
<https://doi.org/10.1144/SP465.6>

Burns, T., Cosgrove, J., Doyle, F., 2019. A Review of Interoperability Standards for Industry 4.0. *Procedia Manuf.* 38, 646–653.

Chauhan, C., Singh, A., Luthra, S., 2021. Barriers to industry 4.0 adoption and its performance implications: An empirical investigation of emerging economy. *J. Clean. Prod.* 285, 124809.

Cillari, A., Stephens, S., Werner, A., 2021. Best practice in license allocation in the oil and gas industry: A review of five countries. *Resour. Policy* 74, 102296.

Correia, M.G., Maleki, M., da Silva, F.B.M., Gomes, A.D., Schiozer, D.J., 2023. Integrated approach to improve simulation models in a deep-water heavy oil field with 4D seismic monitoring. *Pet. Geosci.* 29, petgeo2022-048.

Cowan, J., n.d. The fundamental reason why your geological models may be completely wrong.

Craig, A.B., 2013. Understanding augmented reality: Concepts and applications.

Craig, J., Gerali, F., Macaulay, F., Sorkhabi, R., 2018. The history of the European oil and gas industry (1600s-2000s). *Geol. Soc. Spec. Publ.* 465, 1–24.
<https://doi.org/10.1144/SP465.23>

D’Almeida, A.L., Bergiante, N.C.R., de Souza Ferreira, G., Leta, F.R., de Campos Lima, C.B., Lima, G.B.A., 2022. Digital transformation: a review on artificial intelligence techniques in drilling and production applications. *Int. J. Adv. Manuf. Technol.* 119, 5553–5582.

Dalenogare, L.S., Benitez, G.B., Ayala, N.F., Frank, A.G., 2018. The expected contribution of Industry 4.0 technologies for industrial performance. *Int. J.*

Prod. Econ. 204, 383–394.

Das, S., Mitra, K., Mandal, M., 2016. Sample size calculation: Basic principles. Indian J. Anaesth. 60, 652.

Datta, A., Rousset, J.-M., 2017. From Reactive To Proactive: Talent Management in the “New Normal” for Oil and Gas, in: World Petroleum Congress. WPC, p. D033S018R001.

Dluhopolskyi, O., Prykhodchenko, S., Martynenko, A., Prykhodchenko, O., Asotskyi, V., Zaika, L., 2019. Application of augmented reality for the training of geologist students.

Doveton, J.H., 2001. All Models Are Wrong, but Some Models Are Useful:" Solving" the Simandoux Equation, in: J. of the International Association for Mathematical Geology Conference, Cancun, Mexico. Citeseer.

Elijah, O., Ling, P.A., Rahim, S.K.A., Geok, T.K., Arsad, A., Kadir, E.A., Abdurrahman, M., Junin, R., Agi, A., Abdulfatah, M.Y., 2021. A survey on industry 4.0 for the oil and gas industry: Upstream sector. IEEE Access 9, 144438–144468.

Epstein, A., 2022. Fossil Future: Why Global Human Flourishing Requires More Oil, Coal, and Natural Gas--Not Less. Penguin.

Eurostat, 2023. Oil and petroleum products - a statistical overview [WWW Document]. EuroStrat. URL https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Oil_and_petroleum_products_-_a_statistical_overview#Oil_imports_dependency

Fanchi, J.R., Pagano, T.A., Davis, T.L., 1999. State of the art of 4D seismic monitoring: the technique, the record, and the future. Oil Gas J. 97, 38–43.

Fetzer, J.H., Fetzer, J.H., 1990. What is Artificial Intelligence? Springer.

Furstenau, L.B., Sott, M.K., Kipper, L.M., Machado, E.L., Lopez-Robles, J.R., Dohan, M.S., Cobo, M.J., Zahid, A., Abbasi, Q.H., Imran, M.A., 2020. Link between sustainability and industry 4.0: trends, challenges and new perspectives. IEEE Access 8, 140079–140096.

- Gilchrist, A., 2016a. Introducing Industry 4.0, in: Industry 4.0. Springer, pp. 195–215.
- Gilchrist, A., 2016b. Industry 4.0: the industrial internet of things. Springer.
- Gonzales, J.S., Thune, T., Engen, O.A., Wicken, O., 2018. Cost-cutting as and innovation driver among suppliers during an industry downturn. *Pet. Ind. Transform. Lessons from Norw. Beyond 1*, 70–83.
- Gray, K., Thompson, C., Clerehan, R., Sheard, J., Hamilton, M., 2008. Web 2.0 authorship: Issues of referencing and citation for academic integrity. *Internet High. Educ.* 11, 112–118.
- Gromova, E.A., Koneva, N.S., Titova, E. V, 2022. Legal barriers to the implementation of digital industry (Industry 4.0) components and ways to overcome them. *J. World Intellect. Prop.* 25, 186–205.
- Guyot Phung, C., 2019. Implications of the circular economy and digital transition on skills and green jobs in the plastics industry [WWW Document]. *F. Actions Sci. Reports. J. F. Actions*.
- Hassan, A., 2013. Review of the global oil and gas industry: a concise journey from ancient time to modern world. *Pet. Technol. Dev. J.* 3, 123–141.
- Havard, V., Jeanne, B., Lacomblez, M., Baudry, D., 2019. Digital twin and virtual reality: a co-simulation environment for design and assessment of industrial workstations. *Prod. Manuf. Res.* 7, 472–489.
- Herkenhoff, L., 2018. A profile of the oil and gas industry: Resources, market forces, geopolitics, and technology. Business Expert Press.
- Hilbert, M., López, P., 2011. The world’s technological capacity to store, communicate, and compute information. *Science* (80-.). 332, 60–65.
- Horváth, D., Szabó, R.Z., 2019. Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? *Technol. Forecast. Soc. Change* 146, 119–132.
- Hossain, M.E., 2015. Drilling costs estimation for hydrocarbon wells. *J. Sustain.*

Energy Eng. 3, 3–32.

Howe, R.J., 1986. Evolution of offshore drilling and production technology, in: Offshore Technology Conference. OTC, p. OTC-5354.

Hsieh, F.Y., Bloch, D.A., Larsen, M.D., 1998. A simple method of sample size calculation for linear and logistic regression. *Stat. Med.* 17, 1623–1634.

International Standards Organisation, 2018. Production assurance and reliability management.

International Standards Organisation, 2016. Petroleum, petrochemical and natural gas industries.

Janicke, M., Jacob, K., 2013. A third industrial revolution. *Long-term Gov. Soc. Chang.* 47–71.

Jefferson, M., 2019. Whither Plastics?—Petrochemicals, plastics and sustainability in a garbage-riddled world. *Energy Res. Soc. Sci.* 56, 101229.

Jevons, H.S., 1931. The second industrial revolution. *Econ. J.* 41, 1–18.

Kaplan, J., 2016. Artificial intelligence: What everyone needs to knowR. Oxford University Press.

Karekezi, S., 2002. Renewables in Africa—meeting the energy needs of the poor. *Energy Policy* 30, 1059–1069.

Kaya, S.K., Paksoy, T., Garza-Reyes, J.A., 2020. The new challenge of industry 4.0. *Logistics* 4, 51.

Kellogg, R., 2014. The effect of uncertainty on investment: Evidence from Texas oil drilling. *Am. Econ. Rev.* 104, 1698–1734.

Kent, P.E., 1985. UK onshore oil exploration, 1930-1964. *Mar. Pet. Geol.* 2, 56–64.
[https://doi.org/10.1016/0264-8172\(85\)90048-0](https://doi.org/10.1016/0264-8172(85)90048-0)

Kleinberg, R., Fagan, M., 2019. Business Cycles and Innovation Cycles in the US Upstream Oil & Gas Industry.

- Kramp, T., Van Kranenburg, R., Lange, S., 2013. Introduction to the Internet of Things. Enabling things to talk Des. IoT Solut. with IoT Archit. Ref. Model 1–10.
- Kumar, P., Bhamu, J., Sangwan, K.S., 2021. Analysis of barriers to Industry 4.0 adoption in manufacturing organizations: An ISM approach. *Procedia CIRP* 98, 85–90.
- Kurniawan, T.A., Othman, M.H.D., Hwang, G.H., Gikas, P., 2022. Unlocking digital technologies for waste recycling in Industry 4.0 era: A transformation towards a digitalization-based circular economy in Indonesia. *J. Clean. Prod.* 357, 131911.
- Laborie, F., Røed, O.C., Engdahl, G., Camp, A., 2019. Extracting value from data using an industrial data platform to provide a foundational digital twin, in: *Offshore Technology Conference*. OTC, p. D011S010R005.
- Lee, S., Suh, J., Park, H.-D., 2015. BoreholeAR: A mobile tablet application for effective borehole database visualization using an augmented reality technology. *Comput. Geosci.* 76, 41–49.
- Li, Z., Li, Q., Chen, T., 2024. Record-breaking high-temperature outlook for 2023: An assessment based on the China global Merged Temperature (CMST) dataset. *Adv. Atmos. Sci.* 41, 369–376.
- Lin, G., Fu, D., Zhu, J., Dasmalchi, G., 2009. Cloud computing: IT as a service. *IT Prof.* 11, 10–13.
- Lu, H., Guo, L., Azimi, M., Huang, K., 2019. Oil and Gas 4.0 era: A systematic review and outlook. *Comput. Ind.* 111, 68–90.
- Lukawski, M.Z., Anderson, B.J., Augustine, C., Capuano Jr, L.E., Beckers, K.F., Livesay, B., Tester, J.W., 2014. Cost analysis of oil, gas, and geothermal well drilling. *J. Pet. Sci. Eng.* 118, 1–14.
- Mapako, M., Mbewe, A., 2013. *Renewables and energy for rural development in Sub-Saharan Africa*. Zed Books Ltd.
- Massaro, M., Secinaro, S., Dal Mas, F., Brescia, V., Calandra, D., 2021. Industry 4.0

- and circular economy: An exploratory analysis of academic and practitioners' perspectives. *Bus. Strateg. Environ.* 30, 1213–1231.
- Mathiesen, D., Myers, T., Atkinson, I., Trevathan, J., 2012. Geological visualisation with augmented reality, in: 2012 15th International Conference on Network-Based Information Systems. IEEE, pp. 172–179.
- Maugeri, L., 2012. Oil: the next revolution. *Harvard Kennedy Sch.* 52.
- Mert, U., 2016. The impact of the global financial crisis on crude oil price volatility. *J. Manag. Econ. Res.* 14, 64–76.
- Mian, S.H., Salah, B., Ameen, W., Moiduddin, K., Alkhalefah, H., 2020. Adapting universities for sustainability education in industry 4.0: Channel of challenges and opportunities. *Sustainability* 12, 6100.
- Milkov, A. V, Samis, J.M., 2020. Turning dry holes from disasters to exploration wisdom: Decision tree to determine the key failure mode for segments in conventional petroleum prospects. *Am. Assoc. Pet. Geol. Bull.* 104, 449–475.
- Mohajan, H., 2021. Third industrial revolution brings global development.
- Mohajan, H., 2019. The first industrial revolution: Creation of a new global human era.
- Moid, S., 2020. Education 4.0: Future of Learning With Disruptive Technologies, in: *Promoting Inclusive Growth in the Fourth Industrial Revolution*. IGI Global, pp. 181–200.
- Mokyr, J., Strotz, R.H., 1998. The second industrial revolution, 1870-1914. *Stor. dell'economia Mond.* 21945.
- Müller, C., Townsend, K., Matschullat, J., 2012. Experimental degradation of polymer shopping bags (standard and degradable plastic, and biodegradable) in the gastrointestinal fluids of sea turtles. *Sci. Total Environ.* 416, 464–467.
- Müller, J.M., 2019. Assessing the barriers to Industry 4.0 implementation from a workers' perspective. *IFAC-PapersOnLine* 52, 2189–2194.

- Oddo, J.E., Tomson, M.B., 1994. Why scale forms in the oil field and methods to predict it. *SPE Prod. Facil.* 9, 47–54.
- Olneva, T., Kuzmin, D., Rasskazova, S., Timirgalin, A., 2018. Big data approach for geological study of the big region West Siberia, in: *SPE Annual Technical Conference and Exhibition*. OnePetro.
- Orzes, G., Rauch, E., Bednar, S., Poklemba, R., 2018. Industry 4.0 implementation barriers in small and medium sized enterprises: A focus group study, in: *2018 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*. IEEE, pp. 1348–1352.
- Özdemir, V., Hekim, N., 2018. Birth of industry 5.0: Making sense of big data with artificial intelligence, “the internet of things” and next-generation technology policy. *Omi. a J. Integr. Biol.* 22, 65–76.
- Park, D.S., 2018. Future computing with IoT and cloud computing. *J. Supercomput.* 74, 6401–6407.
- Patidar, A.K., Agarwal, U., Das, U., Choudhury, T., 2024. Understanding the Oil and Gas Sector and Its Processes: Upstream, Downstream, in: *Understanding Data Analytics and Predictive Modelling in the Oil and Gas Industry*. CRC Press, pp. 1–20.
- PK, F.A., 1984. What is artificial intelligence? “Success is no Accid. It is hard Work. perseverance, Learn. studying, Sacrif. Most all, love what you are doing or Learn. to do”. 65.
- Putnik, G.D., Ferreira, L., Lopes, N., Putnik, Z., 2019. What is a Cyber-Physical System: Definitions and models spectrum. *Fme Trans.* 47, 663–674.
- R&D Today, 2019. What is the impact of Industry 4.0 on innovation design processes? [WWW Document]. R&D Today Online. URL <https://www.rndtoday.co.uk/latest-news/what-is-the-impact-of-industry-4-0-on-innovation-design-processes/>
- Raj, A., Dwivedi, G., Sharma, A., de Sousa Jabbour, A.B.L., Rajak, S., 2020. Barriers to

- the adoption of industry 4.0 technologies in the manufacturing sector: An inter-country comparative perspective. *Int. J. Prod. Econ.* 224, 107546.
- Rajput, S., Singh, S.P., 2021. Industry 4.0– challenges to implement circular economy. *Benchmarking An Int. J.* 28, 1717–1739.
- Rajput, S., Singh, S.P., 2019. Connecting circular economy and industry 4.0. *Int. J. Inf. Manage.* 49, 98–113.
- Ripple, W.J., Wolf, C., Gregg, J.W., Rockström, J., Newsome, T.M., Law, B.E., Marques, L., Lenton, T.M., Xu, C., Huq, S., 2023. The 2023 state of the climate report: Entering uncharted territory. *Bioscience* 73, 841–850.
- Rose, K., Eldridge, S., Chapin, L., 2015. The internet of things: An overview. *internet Soc.* 80, 1–50.
- Sea Turtle Biologist, 2015. Sea Turtle with Straw up its Nostril - “NO” TO SINGLE-USE PLASTIC [WWW Document]. YouTube. URL <https://www.youtube.com/watch?v=4wH878t78bw&t=0s>
- Shahrubudin, N., Lee, T.C., Ramlan, R., 2019. An overview on 3D printing technology: Technological, materials, and applications. *Procedia Manuf.* 35, 1286–1296.
- Sharma, M., Joshi, S., Prasad, M., Bartwal, S., 2023. Overcoming barriers to circular economy implementation in the oil & gas industry: Environmental and social implications. *J. Clean. Prod.* 391, 136133.
- Sircar, A., Yadav, K., Rayavarapu, K., Bist, N., Oza, H., 2021. Application of machine learning and artificial intelligence in oil and gas industry. *Pet. Res.* 6, 379–391.
- Skobelev, P.O., Borovik, S.Y., 2017. On the way from Industry 4.0 to Industry 5.0: From digital manufacturing to digital society. *Ind. 4.0* 2, 307–311.
- Ślusarczyk, B., 2018. Industry 4.0: Are we ready? *Polish J. Manag. Stud.* 17.
- Soukupová, N., Adamová, M., Krninská, R., 2020. Industry 4.0: an Employee Perception (Case of the Czech Republic). *Acta Univ. Agric. Silvic. Mendelianae*

Brun. 68.

Stearns, P.N., 2020. The industrial revolution in world history. Routledge.

Stentoft, J., Aadsbøll Wickstrøm, K., Philipsen, K., Haug, A., 2021. Drivers and barriers for Industry 4.0 readiness and practice: empirical evidence from small and medium-sized manufacturers. *Prod. Plan. Control* 32, 811–828.

Stern, D.I., Kander, A., 2012. The role of energy in the industrial revolution and modern economic growth. *Energy J.* 33, 125–152.

Stevens, P., 2018. The role of oil and gas in the economic development of the global economy. *Extr. Ind.* 71, 1–746.

Su, A., Al'Aref, S.J., 2018. History of 3D printing, in: *3D Printing Applications in Cardiovascular Medicine*. Elsevier, pp. 1–10.

Sullivan, G.M., Artino Jr, A.R., 2013. Analyzing and interpreting data from Likert-type scales. *J. Grad. Med. Educ.* 5, 541–542.

Sumbal, M.S., Tsui, E., See-to, E., Barendrecht, A., 2017. Knowledge retention and aging workforce in the oil and gas industry: a multi perspective study. *J. Knowl. Manag.* 21, 907–924.

Tariq, Z., Aljawad, M.S., Hasan, A., Murtaza, M., Mohammed, E., El-Husseiny, A., Alarifi, S.A., Mahmoud, M., Abdulraheem, A., 2021. A systematic review of data science and machine learning applications to the oil and gas industry. *J. Pet. Explor. Prod. Technol.* 1–36.

Telukdarie, A., Buhulaiga, E., Bag, S., Gupta, S., Luo, Z., 2018. Industry 4.0 implementation for multinationals. *Process Saf. Environ. Prot.* 118, 316–329.

The Investopedia Team, 2023. What Percentage of the Global Economy Is the Oil and Gas Drilling Sector? [WWW Document]. Investopedia.com. URL <https://www.investopedia.com/ask/answers/030915/what-percentage-global-economy-comprised-oil-gas-drilling-sector.asp>

Thomas, G.O., Sautkina, E., Poortinga, W., Wolstenholme, E., Whitmarsh, L., 2019.

- The English plastic bag charge changed behavior and increased support for other charges to reduce plastic waste. *Front. Psychol.* 10, 266.
- Troxler, P., 2013. Making the third industrial revolution. *Fab Labs Mach. Makers Invent. Transcr. Publ.* 181–194.
- Ukwandu, D.C., 2018. Absence of electricity as a barrier to inclusive growth and development in Nigeria. *African J. Public Aff.* 10, 23–42.
- Ularu, E.G., Puican, F.C., Apostu, A., Velicanu, M., 2012. Perspectives on big data and big data analytics. *Database Syst. J.* 3, 3–14.
- US Department of Energy, 2019. Products made from oil and natural gas [WWW Document]. Dep. Energy. URL [https://www.energy.gov/sites/prod/files/2019/11/f68/Products Made From Oil and Natural Gas Infographic.pdf](https://www.energy.gov/sites/prod/files/2019/11/f68/Products_Made_From_Oil_and_Natural_Gas_Infographic.pdf)
- Voigt, P., Moncada-Paternò-Castello, P., 2009. The global economic and financial downturn: What does it imply for firms' R&D strategies? IPTS Working Papers on Corporate R&D and Innovation.
- Wanasinghe, T.R., Wroblewski, L., Petersen, B.K., Gosine, R.G., James, L.A., De Silva, O., Mann, G.K.I., Warrian, P.J., 2020. Digital twin for the oil and gas industry: Overview, research trends, opportunities, and challenges. *IEEE access* 8, 104175–104197.
- Wie, K.K.N., 2015. Decision-making on downsizing in an industry specific downturn: a qualitative study on the Norwegian petroleum sector's decision-making on downsizing following the drop in the oil price.
- Wilcox, C., Puckridge, M., Schuyler, Q.A., Townsend, K., Hardesty, B.D., 2018. A quantitative analysis linking sea turtle mortality and plastic debris ingestion. *Sci. Rep.* 8, 12536.
- Winegard, T.C., 2016. The first world oil war. University of Toronto Press.
- Wohlgenannt, I., Simons, A., Stieglitz, S., 2020. Virtual reality. *Bus. Inf. Syst. Eng.* 62, 455–461.

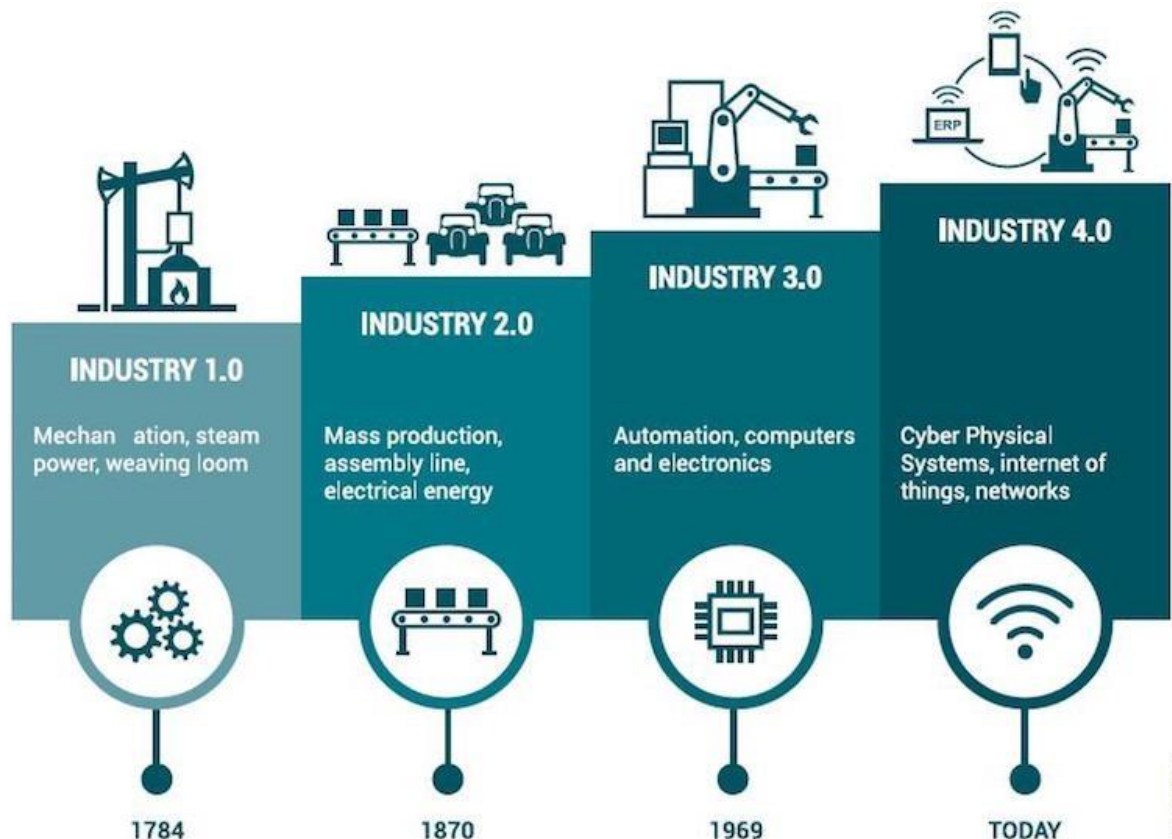
- Wolf, W., 2009. Cyber-physical systems. *Computer* (Long. Beach. Calif). 42, 88–89.
- World Bank, 2023. World Bank “Oil Rents % of GDP” [WWW Document]. World Bank Data. URL <https://data.worldbank.org/indicator>
- Xu, X., Lu, Y., Vogel-Heuser, B., Wang, L., 2021. Industry 4.0 and Industry 5.0—Inception, conception and perception. *J. Manuf. Syst.* 61, 530–535.
- Yang, C., Huang, Q., Li, Z., Liu, K., Hu, F., 2017. Big Data and cloud computing: innovation opportunities and challenges. *Int. J. Digit. Earth* 10, 13–53.
- Yaw Obeng, G., Donkor, P., Quansah, J., 2011. NEEDS ASSESSMENT OF CAPACITY BUILDING FOR CLUSTER DEVELOPMENT IN THE METAL FABRICATION SUB-SECTOR IN THE KUMASI METROPOLIS, GHANA.
<https://doi.org/10.13140/RG.2.1.4835.8009>
- Zukas, V., Zukas, J.A., 2015. An introduction to 3D printing. First Edition Design Pub.

10 Appendices

Enclosure 1 – Blank survey form (questions were repeated on an online Microsoft Form to allow for quicker data collection, and collection across multiple sites).

Evaluating perceptions of Industry 4.0+ technologies with employees

Research Background:



Industry 4.0 is the term given to the latest industrial revolution. In recent human history there have been four industrial revolutions.

Industry 4.0 takes advances in automation and digitalisation that were made in the third industrial revolution, with the aim of increasing operational efficiency of companies. Unlike previous industrial revolutions, part of the Industry 4.0 philosophy aims to close the loop between business operations & environmental impacts by creating/implementing circular economy workflows.

Whilst it will be impossible until long into the future to evaluate the effectiveness of Industry 4.0 implementation, this survey aims to evaluate the current perception and feeling towards Industry 4.0 technology from employees specifically from oil and gas service companies.

Further background information about Industry 4.0 can be found at the following links:

<https://www.ibm.com/topics/industry-4-0>

<https://www.forbes.com/sites/bernardmarr/2018/09/02/what-is-industry-4-0-heres-a-super-easy-explanation-for-anyone/?sh=478d13ee9788>

Research Participation Terms:

This survey will run until Monday 18th December at 5pm. All data will only be used for the purposes of anonymous data for research purposes only relating to James Scorgie's (herein referred to as 'the researcher') MADE International Innovation and Business Management MSc Dissertation.

All data will be anonymised and no personal data will be published in the public domain or be shared with PetroStrat managers. Data will be viewed by the researcher (James Scorgie) and may be viewed by University staff members (such as the researcher's supervisors). The data will then be securely stored and not shared with any third party, once the research has been completed the data will be destroyed. By choosing to complete the survey you consent to your data being used as part of the researcher's research study, completion by staff is entirely voluntary and can be withdrawn at any time.

If you choose to enter, there will be a giveaway for a Toblerone chocolate bar (or equivalent from your local Amazon) which I'll post to you!

If you have any concerns regarding this survey, please contact myself (the researcher) directly via email at 2113853@student.uwtsd.ac.uk.

1. Which department do you spend most of your time working for? (please circle)

- Reservoir Geology
- Micropaleontology
- Nannopaleontology
- Palynology
- New Ventures
- Admin (HR, Finance, management, etc)
- Labs
- Business Development
- Other (please specify)

2. What is your age? (please circle)

- Under 18
- 18 – 24
- 25 – 34
- 35 – 44
- 45 – 54
- 55 – 64
- 65+

3. Have you heard of Industry 4.0 before? (please circle)

- Yes
- No

4. Please rate these statements with how much you agree with the statements.

(If you have multiple roles in the same job, please answer the statements according to your role in which you spend the most time.)

Please tick how strongly you agree with the following statements:					
Statement	Strongly Disagree	Disagree	Neither Agree or	Agree	Strongly Agree
Changes that occur from industrial revolutions are necessary to advance society					
Advancements in automation pose a risk to jobs OVERALL					
Advancements in automation pose a risk to MY JOB					
Businesses will use Industry 4.0 technology to reduce headcounts					
I am willing to learn new skills to ease the transition into an Industry 4.0 workplace					
I will try to avoid using Industry 4.0 technology in the workplace					

5. Final question! Do you own any smart technology? (e.g. Smart Speaker, Smartphone, etc.)

- Yes
- No

Enclosure 2 – Raw data from survey captured from the paper survey or Microsoft Forms (online form).

ID	Start time	Completion time	Which department do you spend most of your time working for?	What is your age?	Have you heard of Industry 4.0 before?	Changes that occur from industrial revolutions are necessary to advance society	Advancements in automation pose a risk to jobs OVERALL	Advancements in automation pose a risk to MY JOB	Businesses will use Industry 4.0 technology to reduce headcounts	I am willing to learn new skills to ease the transition into an Industry 4.0 workplace	I will try to avoid using Industry 4.0 technology in the workplace	Final question! Do you own any smart technology? (e.g. Smart Speaker, Smartphone, etc.)
1	12/11/23 10:32:46	12/11/23 10:43:55	Reservoir Geology	35-44	No	Disagree	Agree	Agree	Agree	Strongly Agree	Disagree	Yes
2	12/11/23 16:30:37	12/11/23 16:33:40	Palynology	35-44	No	Agree	Agree	Neither agree or disagree	Agree	Agree	Neither agree or disagree	Yes
3	12/11/23 16:34:12	12/11/23 16:35:48	Reservoir Geology;	35-44	No	Agree	Disagree	Disagree	Neither agree or disagree	Neither agree or disagree	Neither agree or disagree	Yes
4	12/11/23 16:34:37	12/11/23 16:37:57	Palynology;	35-44	No	Agree	Strongly Agree	Neither agree or disagree	Neither agree or disagree	Agree	Neither agree or disagree	Yes
5	12/11/23 16:48:41	12/11/23 16:50:54	Reservoir Geology;	35-44	No	Disagree	Agree	Agree	Agree	Agree	Disagree	Yes
6	12/11/23 16:51:14	12/11/23 16:53:34	New Ventures;	25-34	Yes	Strongly Agree	Agree	Neither agree or disagree	Agree	Strongly Agree	Neither agree or disagree	Yes
7	12/11/23 17:40:12	12/11/23 17:46:17	Reservoir Geology;	45-54	Yes	Agree	Strongly Agree	Disagree	Agree	Strongly Agree	Strongly Disagree	Yes
8	12/11/23 17:35:15	12/11/23 17:47:38	Reservoir Geology;	55-64	No	Disagree	Strongly Agree	Disagree	Agree	Neither agree or disagree	Disagree	Yes
9	12/12/23 0:22:36	12/12/23 0:27:29	Reservoir Geology;	35-44	No	Disagree	Disagree	Disagree	Neither agree or disagree	Neither agree or disagree	Neither agree or disagree	Yes
10	12/12/23 9:01:03	12/12/23 9:03:29	Reservoir Geology;	45-54	No	Strongly Agree	Disagree	Agree	Strongly Agree	Strongly Agree	Strongly Disagree	Yes
11	12/12/23 9:02:40	12/12/23 9:04:15	Palynology;	25-34	No	Agree	Agree	Disagree	Neither agree or disagree	Agree	Neither agree or disagree	Yes
12	12/12/23 9:02:07	12/12/23 9:04:35	Admin (HR, Finance, etc);	55-64	No	Agree	Disagree	Disagree	Neither agree or disagree	Agree	Neither agree or disagree	No
13	12/12/23 9:01:23	12/12/23 9:05:36	Palynology;	35-44	Yes	Disagree	Agree	Neither agree or disagree	Strongly Agree	Strongly Agree	Disagree	Yes
14	12/12/23 9:04:22	12/12/23 9:06:42	Labs;	35-44	No	Agree	Neither agree or disagree	Disagree	Agree	Agree	Strongly Agree	Yes
15	12/12/23 9:10:50	12/12/23 9:11:20	Reservoir Geology;	25-34	Yes	Strongly Agree	Agree	Neither agree or disagree	Agree	Strongly Agree	Strongly Disagree	Yes
16	12/12/23 9:11:04	12/12/23 9:12:59	Micropalaeontology;	25-34	No	Neither agree or disagree	Strongly Agree	Disagree	Neither agree or disagree	Neither agree or disagree	Neither agree or disagree	Yes
17	12/12/23 9:12:33	12/12/23 9:14:16	Micropalaeontology;	25-34	No	Agree	Strongly Agree	Agree	Agree	Strongly Agree	Strongly Disagree	Yes
18	12/12/23 9:11:44	12/12/23 9:14:46	Labs;	45-54	No	Neither agree or disagree	Neither agree or disagree	Neither agree or disagree	Neither agree or disagree	Neither agree or disagree	Neither agree or disagree	No
19	12/12/23 9:11:44	12/12/23 9:14:51	New Ventures;	55-64	Yes	Agree	Strongly Disagree	Strongly Disagree	Disagree	Strongly Agree	Strongly Disagree	Yes
20	12/12/23 9:13:05	12/12/23 9:15:16	Micropalaeontology;	35-44	No	Strongly Agree	Disagree	Disagree	Neither agree or disagree	Agree	Disagree	Yes
21	12/12/23 9:23:12	12/12/23 9:25:29	Micropalaeontology;	35-44	No	Agree	Agree	Disagree	Agree	Strongly Agree	Disagree	Yes
22	12/12/23 9:24:54	12/12/23 9:26:08	Business Development;	45-54	No	Agree	Disagree	Disagree	Neither agree or disagree	Agree	Neither agree or disagree	Yes
23	12/12/23 9:28:50	12/12/23 9:31:44	Tech Services;	55-64	Yes	Neither agree or disagree	Disagree	Disagree	Agree	Agree	Disagree	Yes
24	12/12/23 9:59:39	12/12/23 10:02:45	Palynology;	35-44	Yes	Agree	Neither agree or disagree	Agree	Agree	Strongly Agree	Strongly Disagree	Yes
25	12/12/23 10:08:00	12/12/23 10:13:01	Labs;	45-54	No	Agree	Neither agree or disagree	Disagree	Agree	Agree	Disagree	Yes
26	12/12/23 11:21:18	12/12/23 11:23:43	entures;Business Develop	55-64	Yes	Strongly Agree	Neither agree or disagree	Disagree	Disagree	Strongly Agree	Strongly Disagree	Yes
27	12/12/23 11:36:06	12/12/23 11:38:47	Labs;	55-64	No	Agree	Agree	Disagree	Agree	Agree	Disagree	Yes
28	12/12/23 12:30:45	12/12/23 12:34:00	Admin (HR, Finance, etc);	55-64	No	Strongly Agree	Disagree	Strongly Disagree	Neither agree or disagree	Agree	Disagree	Yes
29	12/12/23 12:39:36	12/12/23 13:12:17	Nannopalaeontology;	45-54	No	Agree	Disagree	Disagree	Agree	Neither agree or disagree	Neither agree or disagree	Yes
30	12/12/23 15:49:51	12/12/23 15:51:01	Business Development;	35-44	No	Agree	Strongly Disagree	Strongly Disagree	Neither agree or disagree	Strongly Agree	Disagree	Yes
31	12/12/23 18:19:05	12/12/23 18:24:40	Palynology;	35-44	No	Agree	Agree	Agree	Neither agree or disagree	Strongly Agree	Disagree	Yes
32	12/13/23 8:54:58	12/13/23 8:56:33	Micropalaeontology;	35-44	No	Agree	Agree	Disagree	Neither agree or disagree	Agree	Neither agree or disagree	Yes
33	12/13/23 9:10:00	12/13/23 9:11:55	Admin (HR, Finance, etc);	35-44	Yes	Strongly Agree	Disagree	Disagree	Agree	Strongly Agree	Strongly Disagree	Yes
34	12/13/23 10:08:09	12/13/23 10:10:09	Nannopalaeontology;	35-44	No	Agree	Disagree	Disagree	Disagree	Strongly Agree	Strongly Disagree	Yes
35	12/13/23 16:42:23	12/13/23 16:44:31	Reservoir Geology;	25-34	Yes	Strongly Agree	Neither agree or disagree	Agree	Agree	Strongly Agree	Strongly Disagree	Yes
36	12/18/23 15:23:05	12/18/23 15:25:46	Micropalaeontology;	45-54	No	Agree	Agree	Agree	Agree	Agree	Disagree	Yes
37	12/18/23 15:23:54	12/18/23 15:26:10	Admin (HR, Finance, etc);	65+	No	Strongly Agree	Disagree	Strongly Disagree	Disagree	Agree	Disagree	Yes
38	12/18/23 15:22:33	12/18/23 15:27:09	Admin (HR, Finance, etc);	35-44	No	Agree	Agree	Disagree	Agree	Strongly Agree	Disagree	Yes
39	12/18/23 15:29:39	12/18/23 15:31:27	Admin (HR, Finance, etc);	35-44	No	Agree	Disagree	Disagree	Neither agree or disagree	Agree	Disagree	Yes
40	12/18/23 15:37:13	12/18/23 15:39:11	Business operations;	45-54	No	Agree	Neither agree or disagree	Disagree	Agree	Strongly Agree	Strongly Disagree	Yes
41	12/18/23 15:37:34	12/18/23 15:39:34	Labs;	25-34	No	Strongly Agree	Agree	Neither agree or disagree	Neither agree or disagree	Strongly Agree	Neither agree or disagree	Yes
42	12/18/23 15:37:35	12/18/23 15:41:59	New Ventures;	35-44	No	Agree	Strongly Agree	Disagree	Strongly Agree	Agree	Disagree	Yes
43	12/18/23 15:59:49	12/18/23 16:05:48	Labs;	25-34	No	Agree	Agree	Neither agree or disagree	Neither agree or disagree	Agree	Neither agree or disagree	Yes
44	12/19/23 9:10:49	12/19/23 9:13:56	Reservoir Geology;	65+	No	Agree	Agree	Disagree	Neither agree or disagree	Disagree	Agree	No
45	12/19/23 9:55:44	12/19/23 9:58:04	New Ventures;	35-44	Yes	Strongly Agree	Agree	Disagree	Agree	Strongly Agree	Strongly Disagree	Yes

Evaluating perceptions of Industry 4.0+ technologies with employees

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Responses

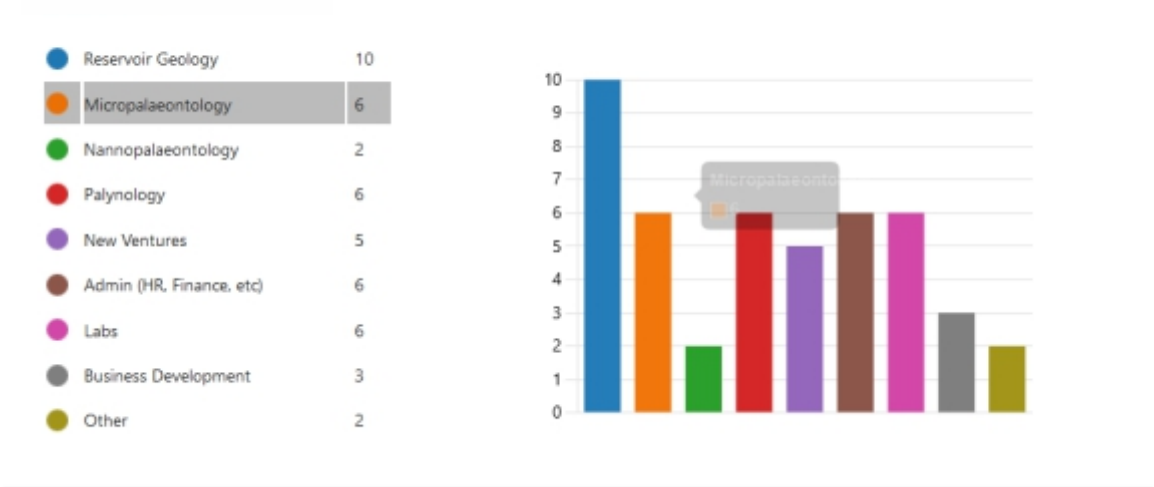
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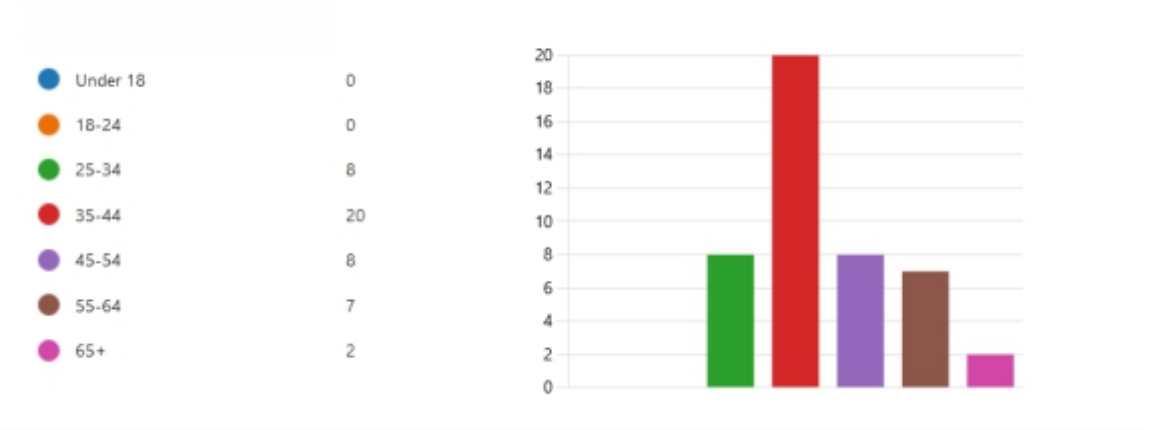
Active

Status

1. Which department do you spend most of your time working for?



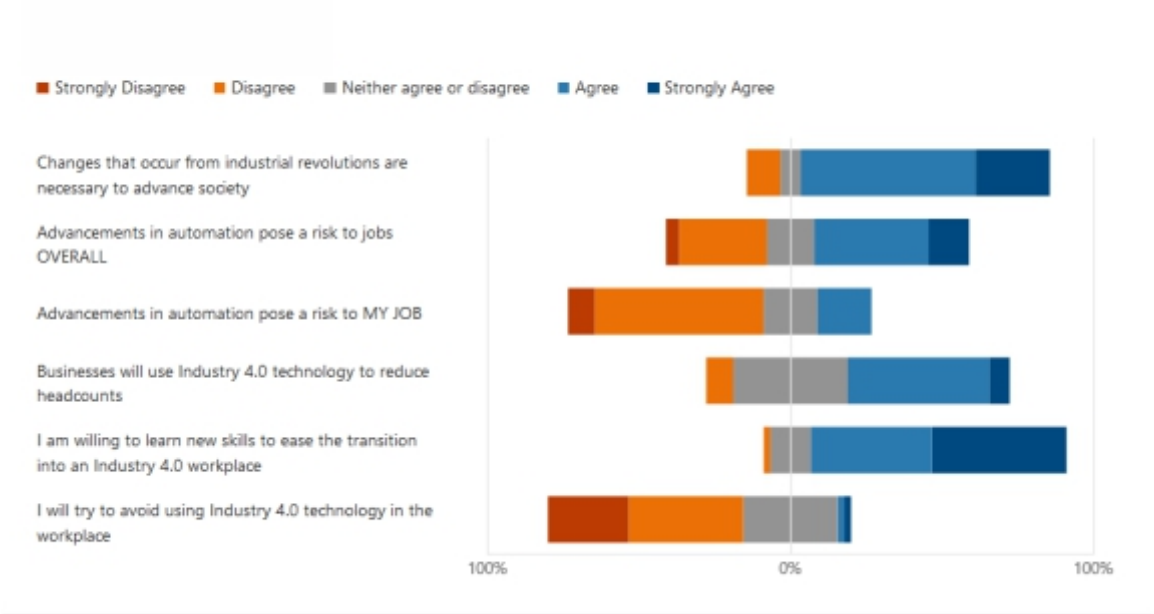
2. What is your age?



3. Have you heard of Industry 4.0 before?



4. Please rate these statements with how much you agree with the statements.



5. Final question! Do you own any smart technology? (e.g. Smart Speaker, Smartphone, etc.)

