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College of Technology and Built Environment

School of Mechanical and Industrial Engineering

Ph.D DISSERTATION

**IMPACT OF LEAN SAFETY FOR OIL AND GAS
INDUSTRY: CASE OF NORTH-SEA UPSTREAM
SECTOR**

By:

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IMPACT OF LEAN SAFETY FOR OIL AND GAS INDUSTRY: CASE OF NORTH-SEA UPSTREAM SECTOR

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Authors' Declarations

*I hereby declare that this dissertation entitled '**Impact of Lean Safety for Oil and Gas Industry: Case of North-Sea Upstream Sector**' is my research work. It has not been, and will not be, submitted in whole or in part to another University for the award of any other degree.*

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Date

*I hereby certify that this dissertation entitled '**Impact of Lean Safety for Oil and Gas Industry: Case of North-Sea Upstream Sector**' is conducted under my supervision. It has not been, and will not be, submitted in whole or in part to another University for the award of any other degree for the Candidate.*

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Abstract

The oil and gas industry upstream exploration and production is one of the most hazardous businesses by the nature of the frontiers materials handled, the contents of the process, and the nature of the working environment and conditions. Moreover, drained profit margin due to low crude oil price arguably compromised safety with a primary focus on project delivery within cost and time budget.

With all the odds and challenges, the sector's stakeholders are applying stringent safety standards, regulations, industry guidelines, and best practices to minimize and avoid workplace injuries to employees. Unfortunately, oil and gas upstream personal injuries are an everyday phenomenon that needs innovative personal safety systems in the sector to bring a paradigm shift in a personal safety system based on every individual involvement, personal engagement, top management leadership, and active participation.

A change in mindset from Safety Compliance to Safety continuous improvement is required. A cultural shift from a top-down management structure to employee engagement and involvement with making safety every individual responsibility must be established to enable safety cultural change in the oil and gas industry.

A workplace with everyone taking responsibility for safety measures results in a safer, more efficient, more productive work environment. It enhances employees' morale, helping a sense of pride in their safety culture and ownership of the safe working environment.

The most popular process continuous improvement methodology and operational excellence methodologies will be used in this dissertation to address the gaps in oil and gas upstream drilling and exploration personal safety systems and personal injury prevention and continuous safety system improvement.

Problem-solving and learning from safe practices, mistakes, incidents, and accidents are important to any continuous improvement process. Lean thinking can turn every incident into a safety improvement opportunity. Learning from losses should never be a blame game but a process review and an improvement initiative. The conventional incident investigation mainly focuses on adverse incidents without learning from the positive developments.

The oil and gas industry needs radical and systematic reform more than ever. As usual, sticking to the old way of working has unsustainable social, economic, environmental, health and safety consequences to the least and detrimental effects to the worst. The industry needs to learn from the experience of other industries, such as manufacturing and healthcare, to be able to ‘do more with less’ by process optimization, value streaming, doing things ‘right the first time,’ doing it safely, and integrating safety in every process, and focusing on safety as a value, etc.

The oil and gas industry is one of the conservative industries with capital-intensive investment and a complex supply chain. The era of ‘easy’ oil and gas access is over. The upstream oil and gas exploration trend has become the most remote place where logistics and transportation are becoming a challenge. Because of thin reserves, wells drilled become long-reach horizontal wells, Deep-Sea, and hostile offshore environments. In these Satellite marginal fields, it is difficult to tie up to existing installation, depleted reservoir with geological, reservoir and other technical characteristics, uncharted environment with attached high safety risk challenges and hazardous conditions and acts where the industry performs exploration activities.

By its nature, the oil and gas industry has a high environmental footprint in terms of carbon emission, uncontrolled spills, and waste disposal. Due to this effect, governing (regulatory) bodies are applying maximum pressure on the industry so that it should minimize the environmental impact due to its operation and apply various innovative techniques such as carbon capturing, carbon trading, and stringent HSE standards and on top of these, focus on clean energy.

For any industry, human capital is one of the important inputs of product and service production. The oil and gas industry is at an immense challenge, as the most experienced and skilled workforce the industry depends on will retire within the coming five to seven years www.forbes.com; Satish Tyagi et al., (2015). Thus, knowledge transfer and successive planning could be a demanding task for an industry that has already faced daunting challenges. Especially experience related to workplace safety practice

The oil and gas industry has been experiencing the longest and toughest downturn by any standard López, (2015); this is the right time for the industry to ‘change for the better; a strategic change is mandatory, not an option. The sector needs an integrated

strategic change that could be expressed in innovating process improvement with personal safety embedded in every process.

The focus of this study is to explore how oil and gas safety systems could be continuously improved beyond the basic safety compliance through employee engagement, employee involvement, and innovative safety system that could be used for oil and gas upstream sector injury prevention, problem-solving, building safe working environment and value addition in the context of oil and gas industry, with particular focus in North-Sea upstream sector.

As any business organizations focus on productivity improvement, product and service quality, and customer services, not least safety is also one of the important business processes that need the involvement of top and frontline employees, with everyone's responsibility, avoiding the common mistake of leaving safety for safety department and safety officers.

In line with this, innovative safety system methodology, tools, and HSE standards are reviewed in the oil and gas industry context, specifically from the point of personal injuries prevention. Innovative safety system implications on the personal safety, safe working environment, value innovation, and environmental contribution of the industry will be assessed, and a conceptual and analytical continuous safety improvement system model will be developed. The conceptual and descriptive research methodology will be applied to evaluate, assess, benchmark, and develop a continuous safety system improvement model that would fit the upstream oil and gas industry context.

In this dissertation, the concept of continuous safety system improvement development from employee engagement and involvement in continuous safety process improvement and learning is considered to positively improve the working environment, safety culture, and workforce morale.

In this dissertation, the Norwegian oil and gas offshore exploration and production sector has been considered close to explore the sectors safety practice from the point of 'respect for people,' continuous improvement, employee involvement, and daily safety practice beyond compliance in general and people-based safety approach in particular through employee engagement and continuous learning.

Key Words: Safety system, lean thinking, continuous improvement, ‘respect for people,’ people-based safety, safety compliance, workplace injuries, machine learning.

Chapter One

1. Background and Justifications of the Study

1.1 Introduction

The petroleum industry is an industry with the potential for major accidents. Studies from Norway and globally show that major accidents often have a complex and complicated course of events and that organizational factors can strongly contribute to the accidents (Norwegian ministry of labor & social affairs, 2018; Laumann et al., 2014; Moura et al., 2016).

To reduce the risk level of fatal and non-fatal injuries, petroleum safety authorities emphasized implementing carefully designed safety management strategies. This dissertation, therefore, addresses how oil and gas upstream safety systems could continuously be innovated, where upstream work processes (exploration, drilling, and production) are streamlined to eliminate process wastes, maximize customer value and employee safety, and give competitive advantages for the company to grow, retain key workforces and win competitions.

Elimination of process waste directly reflects the elimination or minimization of HSE risks and improves operational safety. The results are improved productivity, minimized cost, reduced non-productive time and buy-in from employees, and promoted employee morale.

Initiated by events in the financial sector in 2007 and fueled by the bursting of the U.S. and European housing markets, the global economy fell quickly into the ‘Great Recession,’ considered by the IMF (2009) as the worst global economic decline since World War II, (van Dun et al., 2016). The global economic downturn has affected almost every industry, and the oil and gas industry is no different. The Oil and Gas industry has been in a downturn, one of its kind, which has lasted for a more extended period compared to the previous downturns the industry has faced in recent decades. Cost-cutting, downsizing, merging, and employee layoffs have been some of the common happenings in the industry in recent years.

The oil and gas industry is encountering mixed circumstances, from price fluctuations to demand rebounding after the relaxations of global shutdown measures due to the Covid-19 pandemic, war-related crises between Russia and Ukraine that resulted in the supply issue.

The good news is that it is not all gloomy in the industry. Companies that could adjust their business strategy, Boyle et al., (2011) according to the tide and use this difficult time to their advantage could survive the recession and use the challenge to their advantage to grow stronger and more prosperous. This could happen as far as they adjust their strategy, considering their internal strength and capability aligned to the external opportunity, by mitigating the threat they face in a day-to-day business endeavor.

The current reality in the oil and gas industry is that the industry experiences major to minor accidents and injuries to personnel, high cost of project and operation execution irrespective of the industries effort to minimize accidents to employees, Smith et al., (2019); Kh, A et al., (2019). Changing for the better is mandatory for the very existence of the industry. The Toyota motor company could be the best benchmark that managed to survive the difficult time after WWII, Resta et al., (2015) by modernizing the way of working by introducing the Toyota Production System (TPS) (Liker, 2004).

Researchers from the Massachusetts Institute of Technology (MIT), under a research project which lasted for five years, have identified the success behind Toyota's competitive advantage, Holweg, (2007) and realized that the company's working culture and management system under the umbrella of TPS, was the catalyzing factor. Finally, they coined the production system Lean production (Womack et al. 1990).

Like any other industry, the oil and gas industry was enjoying the upturn with high oil and gas prices, pursuing expensive projects, and generously paying shareholders high dividends and attractive package salaries and bonuses for its employees. Currently, most projects are shelved based on financial viability and prioritizing critical activities and projects deemed to contribute to companies' survival.

The author of this research has a strong belief that this would be the right time to get the buy-in from oil and gas C-level top executives to apply and implement innovative safety systems as part of the business process philosophy for creating customer value

and a safe working environment for the employee's Todd A. et al., (2011). Continuous process improvement methodologies, such as Lean thinking, which has well been tested in the Manufacturing industry, especially the auto industry, and becoming the most popular business philosophy for creating a safe and organized working environment, waste minimization, reducing lead time, promoting employee engagement, offering quality products and services, boost employees morale and value innovation for customers are among the methodologies widely implemented on this research work, (Ohno,1988).

The author argues that Lean thinking and philosophy are not cost-cutting measures, nor is business thinking with a bunch of tools, Hicks (2007). Relatively lean is a business philosophy, the business mindset with a deep-rooted culture of problem-solving and solving problems at the source, by walking to the 'Gemba' the actual place where value is created, with the involvement of top management and front-line employees, in line with the value of the end-user, safe working environment for employees and learning from it and thriving for perfection, (Womack & Jones, 1996).

In today's globalized world of fierce business competition for market share and growth, Amir & Thulasi (2015); Seher & Hatice (2015), firms must devise an innovative way of doing things. To win market competition, grow the business sustainably, and offer their respective customers quality products and services with on-time delivery, boosting employee engagement and morale by creating safety as a firm value. Businesses need to 'do more with less' by using less material, natural resources, and other inputs, keep the well-being of employees, well utilize the talents and inputs, and maintain the ecosystem and environment.

The author of this study is a lean practitioner in the oil and gas industry, working in the most demanding North Sea deep-water frontier. The research idea emanates from the real problems that exist in the industry. As the industry is struggling with a low price of oil and gas, high cost of project development, a safety hazard for employees, minor to major accidents, difficulty in reaching remote oil and gas reserves, stringent regulatory requirements, and informed customers who know what products and service to choose, and society and the public at large who can grant or deny a license to operate.

Business, as usual, has a detrimental consequence on the industry, the industry that is the driving power of the world economy. Thus, it is pertinent to bring a paradigm shift

in the way how things are done by employing a new way of doing things, which enables competitive advantage by resulting in quality products and services with shorter lead time, and high customer value, taking into account a reduced impact on the environment and creating safe working conditions and injury-free workplace for employees. (Kilpatrick, 2003).

1.2 Background of the study

Due to world population growth and related energy demands, the oil and gas industry activities are expanding to deep-water and arctic regions, which are operationally challenging, Schaeffer, (2015); Asif & Muneer, (2007). The technological development and performance in the oil and gas industry are continuously improving. Nevertheless, as the oil and gas reserves are located in remote locations, operational challenges create. Even if the industry uses the most stringent safety standards and regulations, accidents, incidents, near misses, and personnel injuries are still happening daily.

By the nature of the industry's operations, risk, hazards, and general safety management in operation processes are equally important to productivity, product quality, and customer services, Bigliani, (2013); Suda et al., (2015). The common mistake of leaving safety management to the safety department is a traditional view that would not cope with the enormous challenges the industry is currently facing. Safety should be embedded in every organization's processes and need to be the responsibility of every individual in the organization.

The industry's working environment is overrun by various multidimensional hazards ranging from mechanical, ergonomic, electrical, high pressure, chemical, biological, radioactive, explosion, fires, falls, and confined space hazards. Well-organized hazards hunt, pre-task job safety analysis, and risk management to identify, evaluate, control, mitigate and eliminate the risks involved are imperative in the continuous safety improvement of the industry's safety management.

Unfortunately, safety has become a buzzword and gets the most attention from top management, making the news in the aftermath of significant accidents where every player in the industry specializes in investigating what went wrong and the root cause of the accident. There is nothing wrong with the investigation as it would give lessons learned to avoid similar problems. Still, the issue is the investigation, in most cases, mainly focuses on who caused the accident rather than what caused it. This could lead to resistance to finding the root cause and develop a blame culture.

The misconception that equates safety to the absence of accident is a fundamental problem looking into just the tip of the iceberg without noticing the underlying danger

and the problem that hides below the high level of the water. Celebrating many hours of operations with zero injuries is customary, after which a big accident may surprise everyone. Thus, what matters is the safety culture that works in the industry in all situations with a culture of continuous learning from positive safety practices and incidents and a well-established system to report near misses and incidents.

What matters most is not the new policies, rules, regulations, procedures, etc. It is the buy-in from all employees and the initiative to take it personally and engage oneself in the endeavor of safe working practice and protecting oneself and others in the workplace. A safety system needs to include top management and frontline employees' involvement, with top-down and bottom-up feedback systems.

1.2.1 Justification for using the selected safety system improvement methodology

As people are key organization resources that could make or break the organization's goal and objectives, a people-centered safety system with everyone involved is the core of this research's justification. The research borrows key philosophy from lean thinking, 'respect for employees' as a core foundation in building a robust safety system.

For this research, two safety approaches are considered; Safety I and Safety II. In Safety I approach, safety is defined as a state where as few things as possible go wrong. A Safety-I approach presumes that things go wrong because of identifiable failures or malfunctions of specific components: technology, procedures, the human workers, and the organizations in which they are embedded. Humans—are viewed as a hazard in Safety I' (Hollnagel, E. 2012; Hollnagel, E. 2009)

The great difficulty for continuous safety improvement is how activities go right in spite of uncertainties, ambiguities, risks, and generally complex working conditions. This study would address these challenges by proposing a people-based safety system, where the core principle would be 'respect for employees and creating a safety culture of continuous improvement.

A Safety-II approach assumes that' everyday performance variability provides the adaptations needed to respond to varying conditions, which is why things go right. Humans are consequently seen as a resource necessary for system flexibility and resilience. (Finkel, 2011).

Table 1.1: Overview of Safety I and Safety II

	Safety-I	Safety-II
Definition of safety	That as few things as possible go wrong.	That as many things as possible go right.
Safety management principle	Reactive, respond when something happens or is categorized as an unacceptable risk	Proactive, continuously trying to Anticipate developments and events.
View of the human factor in safety management	Humans are predominantly seen as a liability or hazard. They are a problem to be fixed	Humans are seen as a resource necessary for system flexibility and resilience. They provide flexible solutions to many potential problems.
Accident investigation	Failures and malfunctions cause accidents. The purpose of an investigation is to identify the causes	Things happen in the same way, regardless of the outcome. The purpose of an investigation is to understand how things usually go right to explain how things occasionally go wrong.
Risk assessment	Failures and malfunctions cause accidents. The purpose of an investigation is to identify causes and contributory factors.	To understand the conditions where performance variability can become difficult or impossible to monitor and control

Source: (Hollnagel, Braithwaite & Wears, 2013; Wears, Hollnagel & Braithwaite, 2015; Hollnagel, E. 2012; Hollnagel, E. 2009)

There is a common perception among businesses to state safety as their business priority. But it is common sense that priority shifts when something critical comes into the business process. Thus, this dissertation argues that safety needs to be considered as integrated into the business value instead of being a priority and manages the risks uncovered in the various complex processes and variable working conditions.

Lean thinking is the business continuous improvement methodology that comes to everyone's mind for promoting business value. Customer value is one of the five

principles of lean thinking defining business values from customers' perspective (Womack & Jones, (1996). The value concept is core to business strategy. Identifying and creating customer value, defined as value for customers, is an indispensable prerequisite for future company competitive advantage (Graf & Maas, 2008).

Lean is about adding value to the products and services while eliminating waste from processes. As Shook & Rother (1998) phrase it, 'learning to see' is a phrase where firms learn to see hidden wastes. Hidden waste may be driving up the cost of firms' products and services. In order to guarantee long-term survival in today's competitive market environment, businesses must continually reduce process waste (<https://quality-one.com/lean/>).

Lean is a 'revolution' it isn't just about using tools or changing a few steps in the business processes; it's about the complete change along the value chain, how the supply chain works, the working culture, engagement, and involvement of each employee how the top management direct, go about their daily work, how employees ownership of the processes and activities promote safety culture (T. Melton, 2005).

Howell et al. (2017) claim that evidence shows that lean projects are safer. The authors argue that lean projects are safe because of their grounded principles of 'Respect for people.' Respect for People is a fundamental lean principle applicable to all types of organizations and business systems, both project-based and non-project-based, Ohno, (1988); Oppenheim et al. (2011); Cardon & Bribiescas, (2015); Howell et al., (2017). Liker's way of presenting the idea of respect for people is understood to mean challenging, coaching, and training employees and suppliers to improve their capabilities, particularly in problem-solving and process improvement (Liker, 2004).

Edmondson (1999), Bossche et al. (2006), and Howell et al. (2017) reported that psychological safety is crucial for the engagement of learning behaviors in teams, which could result in better team performance. Howell et al. (2017) proposed that employees' actions and behavior according to the lean philosophy of respect for people improve safety by creating the psychological safety needed for learning behaviors within the business that could result in customer value and a safer work environment for the employees.

Camuffo et al. (2017) asserted that high involvement in work practices, employee engagement, continuous coaching and training, employee capability development and empowerment, and autonomy and participation of workers in developing their job standards positively affect occupational safety.

Jilcha & Kitaw (2016) emphasized the importance of lean safety in the workplace by recognizing the less attention given to the methodology in developing countries, taking a case with secondary data from the Ethiopian Ministry of Labor and Social Affairs (MOLSA).

A business with the best strategy, high-quality products, and services would not last long in the fierce market environment if it could not manage to integrate customer value with employees' value expressed in terms of a safe working environment, respect for employees, and engaging employees in process improvements. Safety is a critical element in the lean thinking processes with an effort to yield processes that are better, faster, less wasteful, and safer (Main et al., 2008).

Customer and employee value-focused business strategy would create a win-win situation for all parties involved by creating high-quality products and services for customers and a safer working environment for employees. Employees take full responsibility for the improvement of the work they do and organize their working environment in such a way that they can see process wastes and hazards in the workplace. This is in line with Taubitz's (2010) view that for top management who want to do the right thing for the right reasons, leading lean, green, and safe will result in improved organizational performance. Employees will find work easier and less stressful, and clients and customers will be happy about their improved customer experience.

As discussed earlier, oil and gas operation entails operational risk, negative environmental impact, hazardous conditions, unsafe acts, workplace safety risks, etc. Defects on the system, process wastes related to incidents, accidents and near misses, incident investigation, and activity stops and waiting due to incidents could increase undesired expenditure. Undetected defects and lack of error-proof (Poka Yoke) on some oil and gas activity processes could cause a premature failure that negatively impacts HSE and costs the oil and gas industry a huge amount.

There is an analogy between oil and gas well construction and car manufacturing. In recent years, the applications of Lean thinking in manufacturing and health care have shown impressive results. Therefore, this dissertation will explore applying the lean philosophy in the oil and gas industry to customer value creation and a safe working environment for employees.

The approach would focus on understanding external and internal customer needs and requirements; optimizing product or service value while reducing non-value-added activity; and engaging the organization in identifying and realizing improvement opportunities. Identify risks and implement mitigation measures.

The initiative Equinor has taken to start the application of lean philosophy in its business processes is an exemplifying development for operators and suppliers in North-sea oil and gas operations. Equinor, as a major market-leading operator in North-sea oil and gas activities, has huge leverage on the value chain that would encourage the sector's players to do the same.

This study takes advantage of the Equinor effort of starting a lean thinking application. It reviews the synergy effect of operator-supplier partnership along the oil and gas value chain by benchmarking the experience and learning of the Automobile and Healthcare industry.

The automobile industry is the pioneer in developing operational excellence methodology such as lean thinking. The popularity of the philosophy spread to many industrial and service industries. Increased competition, Seher Arslankaya & Hatice Atay, (2015); Brunilde Verrier et al., (2013) and globalization has raised a need for lower costs and higher quality in producing goods and services, which generally explains the success of Lean as a concept (Hines et al., 2004; Souza, 2009; Drotz, 2014).

Lean originated from the Toyota Production System and was an attempt by Massachusetts Institute of Technology (MIT) scholars to explain the philosophies and practices that made Toyota so successful compared to American and European competitors, Holweg, (2007). The Toyota Production System consists of two major ideas: Respect for people and continuous improvement (Toyota Way, 2001).

The workforces of an organization are the most valuable asset that could give a competitive advantage over the competitors, Tenera & Pinto, (2014); Rohania & Zahraeea, (2015). The ideas behind respect for people and continuous improvement are employees' engagement and develop employees, leaders, and suppliers. At the same time, the latter is related to production processes and how to improve them continuously. In this respect, Lean should be viewed as a system and developing process strongly related to developing people (Liker, 2004).

The current global market environment is highly competitive. It is no longer a guarantee to be a market leader or innovator in some products or services proposition, as the

dynamic nature of the market would lead to new players and market situation as the days pass by. Therefore, the need for flexibility to handle the changing business environment is in an organization's best interest. In many cases, business owners and shareholders demand constant profit from investments, sometimes focusing on long-term and short-term interests. Either company prevails and handles the ever-changing market environment by adapting to the dynamic nature of the external and internal organizational situation, or they would perish and go bankrupt or operate an ever-declining business. Organizations are struggling, facing challenges from customer-driven and global competitive markets (Bahmu & Sangwan, 2014; Manfredsson, 2016).

The North Sea upstream oil and gas industry is the focus of this study. The paramount continuous improvements, Pampanelli et al. (2013), which the automobile industry has achieved, would be the best benchmarking practice for the oil and gas industry value innovation from the context of customer value and employee value that could be expressed in a safe working environment for the employees. The current low crude oil price, which has lasted longer than the usual cyclic downturn, has been a big challenge for the industry players, irrespective of market size and geographical region. The industry would not tackle the cyclic nature of business challenges with common fixes that could not bring a sustainable competitive advantage.

The author of this study strongly asserts that continuous process improvement methodologies such as lean philosophy would be the best-fit methodology and practice that could bring a continuous improvement and sustainable competitive advantage for the industry, which has long been in a downturn, and prone to recurrent minor to major accidents.

On a company level, when times are good, the driving force for improvements concerning efficiency is to make better use of resources and enhance profits. In contrast, in times of recession, the driver for improvement is survival in the marketplace, Meiling, (2010). The oil and gas industry, time- and- time again, spend enormously when the crude market is good, freezing most projects when crude price decreases and in a downturn. This trend needs to be leveled to achieve continuous improvement irrespective of the external market situation.

1.3 Statements of the problem

Oil and gas will remain the primary energy source for the coming decades. The industry needs to innovate its processes and safety system to deliver high-quality products and services for the customers and a safe working environment for the employees.

The easy-to-find petroleum resources are no more, and oil and gas companies need to explore remote locations where there is a high risk of disturbing the ecosystem due to the petroleum exploration and production activities and hazardous working environment for the employees.

Oil and gas exploration and production activities are one of the most hazardous activities due to the nature of the industry. Some of the common hazards unique to the sector are: explosions and fires, falls, slips, trips, confined spaces, the hazard from energy sources, and ergonomic hazards. The industry has been using hazard controlling, preventing, and eliminating methods that mainly focus on compliance with regulation, procedures, standards, safety plans, safety meetings, etc. However, these conventional measures have not spared the industry from avoiding safety accidents and injuries. Thus, an innovative paradigm shift is required; this study proposes a focus on people-based safety in-line with operational excellence methodologies ‘respect for employees.

From 1975 to 2012, at least 6,183 offshore accidents were reported, including accidents, incidents, and near misses, the majority in the northern hemisphere ILO, (2016). High Workforce turnover in terms of retirement and people leaving the industry poses a high challenge in workforce successive planning and transfer of best practices. The industry could potentially lose its institutional memory regarding safety and good practices (ILO, 2016).

The ILO (2016) research found an increased chance of illness and injury among employees working long-hour schedules and schedules involving unconventional shift setups, for example, night and evening shifts. Moreover, another thing that needs close evaluation could be concerning working time using employees on an overtime basis. Long working hours often result in adverse effects on the work-life balance.

As per the statistic of fatality from the US, the pioneer of oil and gas industry originator, CDC's Morbidity and Mortality Weekly Report, Apr. (2013), has published an analysis of fatalities in the U.S. oil and gas extraction industry from 2003 to 2010. On-shore and offshore oil and gas operations had a collective fatality rate of 27.1 per 100,000 workers, seven times higher than for all U.S. workers (3.8 deaths per 100,000 workers)

The ILO estimates that some 2.3 million women and men worldwide face deaths due to work-related accidents or diseases yearly; this corresponds to over 6000 deaths daily. Worldwide, around 340 million occupational accidents and 160 million victims of work-related illnesses annually. The ILO updates these estimates at intervals, and the updates indicate an increase in accidents and ill health.

It is factual that any work activity and every industry has its kind of work-related hazards, the oil and gas are not different from this. The question is how to control and eliminate the dangerous acts and conditions to create safe working conditions and value for the workforce. This will be one of the main points of discussion in this dissertation. Safety is a responsibility of every stakeholder and player in the industry: employees, Employers, regulatory-bodies, etc.

Oil and gas are likely to be a significant energy source for decades. But for the industry to be seen as a partner in energy solutions and economic prosperity – rather than a source of workforces health and safety risk and environmental damage, Azadegan et al., (2013) and driver of sectarian conflict – the industry would need to address the severe trust challenges created by the very nature of its operations, (World Economic Forum, 2016).

Competition for natural resources has driven companies to explore and produce in harsh, remote, and even hostile locations, where even the most straightforward supply of material and other resources needed for the operation could be difficult and costly, and the hazardous conditions and act the employees face in everyday operations could be riskier due to the remoteness of the exploration and drilling operation.

The current oil and gas industry operating environment could be expressed as below: as easy to access, reserves are becoming rare and rare, and as the environment grows

more diverse and unforgiving and the challenges become more complex, and on top of that, most skilled workforces are soon leaving the work environment and growing scarce.

Low crude oil prices lead to shrinking margins, growing conflicting interest from various stakeholders, a stringent requirement from an environmental regulatory body, and competition for new technology energy sources. Other internal and external factors have left the industry with no option other than reforming the industry's operational methodology geared to low cost, shorter lead time, and high employee value expressed in terms of a safe working environment Ugarte et al. (2016). Value proposition from customer perspectives, high employee engagement, low carbon footprint, and environmentally friendly operations (IBM Business Consulting Services, 2004).

In the third quarter of 2014, when oil prices were still above \$100 per barrel, the supermajors posted an aggregate net income of \$22.9 billion (Bloomberg). Twelve months later, upstream profits had been wiped out. In response, companies were cutting expenses. More than \$200 billion worth of projects have already been canceled or postponed, PWC, (2017). The drained profit margin, in some cases, force some companies to take shortcuts that could lead to compromised safety measures and hastened operation against time with cost-cutting in mind without proper risk assessment measures.

Both international and national oil companies are negotiating aggressively for 10 to 30 percent discounts from oil-field service providers. Head counts are affected as well. More than 200,000 employees have been laid off in the oil and gas industry, according to recent company announcements Likosky, M. (2010); cnbc.com, (2016). This kind of short-term-focused reaction does not do any strategic benefit for the industry and either not in the best interest of the global economy. The only unintended consequence that would come out of this kind of panicky response could lead to an unprepared industry for the next upturn when demand becomes healthier, and crude prices start picking up (Tan & Mathews, 2010); PWC, 2017).

As a lean practitioner, the author of this dissertation is a problem 'hunter' practicing 'learning to see problems. In Toyota, they call it 'No problem is a problem' because problems are all around us. The only difference is if we can see them because some problems are hidden as 'icebergs.' The oil and gas industry has some common

problems. The problems list could go on and on, but these are the most critical problems one can observe in the industry:

- ✓ The industry, unfortunately, focuses on significant accidents giving less attention to minor accidents and near misses incidents.
- ✓ With an aging workforce, the industry is at risk of losing its most valuable, talented workforce through retirement; one in four industry employees will retire in the coming few years, Szinovacz, (2011). A sustainable knowledge management system is imperative for a well-managed skill, safety management, and technology transfer among various workforce levels.
- ✓ Cyclic Fluctuation of demand and oil Price Caldara et al., (2016); one may think it is beyond the control of the industry to control the cyclic nature of demand and price, but the argument here would be that the industry needs to strategically position itself so that it could well be prepared to dampen the consequence of demand and price fluctuation, by leveling the primary operation of the industry. This could also be expressed concerning the employees' value, where unlevelled activity could trigger employee safety and health issues.
- ✓ Expensive fines related to environmental footprint. It could be a win-win situation for the industry to voluntarily take the initiative to reduce the environmental footprint that operations could cause due to oil and gas operations. On top of that, the Corporate Sustainability Agenda (CSA) could give the public consent to operate and give a strategic advantage to avoid expensive penalties. It is just in everyone's fresh mind what happened in the Gulf of Mexico, and the penalties in relation to the incident shocked the core of BP (On an after-tax basis, BP's spill costs would amount to \$44 billion (Smith et al. 2011; the Washington Post, 2016).
- ✓ Disintegrated multi-supplier customer relationship. Competition along the supply chain is becoming the norm of the day. Supply chain visibilities and information sharing among the supply chain partners and actors are imperative in creating customer value along the value chain and creating a work environment with a safety system contributed by all players. etc. are some of the best-practiced philosophies at the exposure of the industry. The oil and gas

industry has the most complex supply chain; even supplying the most explicit material and other resources for the remote locations of oil and gas operations is becoming a challenge, Aas et al., (2009); IBM Business Consulting Services, (2004). The weak supplier-customer relationship is also visible in work environment safety management.

- ✓ Competition from new Technologies, Long et al., (2012); IntelligentHQ, (2012). For the industry to continue supplying global energy demand, it should convince the end-users to assert in the future of oil and gas as a reliable energy source. The world is closely watching industries like oil and gas in relation to climatic change, workforce safety, and global warming. Oil and gas companies should be part of the solution in a global agenda of maintaining a sustainable ‘mother Earth.’ Some oil and gas companies have already started diversifying their portfolio, including renewable energy sources such as offshore wind energy, using their experience in offshore exploration and drilling projects (www.equinor.com).

The industry which has been the driving power of the global economy, the oil and gas industry, is at a crossroads and facing ever-increasing challenges compounded by internal and external safety and environmental factors, aging installations, aging workforces, fierce competition, internal friction, among the OPEC members.

History is an excellent lesson and living example of how Toyota Motor Corporation had evolved from the big crisis after WWII; Holweg (2007) restructured the companies working system by focusing on customer values and eliminating process wastes, using Toyota Production System (TPS), which is coined as Lean production by MIT scholars, (Womack et al., 1990).

Lean management has its root in manufacturing industries but has been widely spread in other industries, such as Healthcare, government, and other service industries. The author of this study strongly argues that lean thinking could be the best-fit business philosophy that would address numerous challenges the oil and gas industry is currently facing. One of the significant gaps identified through the literature review is that lean thinking is not well-practiced and research in oil and gas (Jasti & Kodali, 2015).

Supply chain integration and supplier-customer collaboration is a competitive advantage that brings value chain synergy, J. Jaklic et al., (2006) in promoting effectiveness and efficiency and safe working culture along the value chain. From the oil and gas exploration and production players' context, value chain integration is one of the key tools to create visibility and learn from each other experience on safety practices.

1.4 Research Questions (RQ)

This study addresses four main research questions, which are basically driven and designed based on critical safety problems that the oil and gas upstream industry is currently challenged with.

RQ1. Why all the safety systems, plans, procedures, and meetings have not spared the industry from embracing workplace injuries?

RQ2. What are the most frequently happening injury types in the oil & and gas upstream sector?

RQ3. What are the parallels between employees based workplace safety system and Continuous improvement 'respect for employees'?

RQ4. What are the continuous improvement tools, techniques, and enablers for promoting Safety across upstream oil and gas?

The list of questions may go on and on, but the study addresses the most crucial ones from the perspectives of workforce safety, workplace injuries prevention, engagement, and value. The influence of customer-supplier relationship, employees' generational gap and knowledge transfer, involvement and engagement, customer value along the value chain and synergy effect, and process waste elimination in upstream oil and gas activity on the industry's workplace safety performance will get coverage in this work.

1.5 General Objectives

Develop continuous safety system improvement to minimize the frequency of minor and near-miss injuries and incidents.

1.5.1 Specific Objectives

The specific objectives of this study are to:

- Identify why safety procedures, plans, instruction, and meetings alone would not spare the sector from embracing workplace injuries.
- Identify employee's body part that is frequently injured
- Identify the synergy effect of lean thinking 'respect for people' to a people-based safety system in the upstream oil and gas industry.
- Evaluate the impact of workforce engagement in upstream oil and gas industry service delivery and safe working condition.
- Identify continuous improvement tools and techniques and enablers that promote workplace safety.
- To explore the general safety practice of oil and gas upstream North-Sea sector and develop a Continuous improvement in the safety system.
- Evaluate the impact of communication clarity in upstream oil and gas service provision and safety practices.
- Evaluate upstream oil and gas sector incidents and accidents from the point of lean thinking, value innovation, and sector continuous learning.
- Build a safety system model within the context of the oil and gas upstream sector

1.6 Scope of the Study

The scope of this study is to explore the general safety practice of the oil and gas upstream North Sea sector and develop a robust safety system for competitive advantages of the oil and gas industry upstream sector. Competitive advantages from the perspective of continuous improvement-based safety implementation, workplace safety, workplace injury identification, workforce engagement, knowledge transfer, operational excellence tools, and techniques for promoting a safety culture. Each of the above competitiveness enabling factors, their drivers, and leading and lagging factors are covered. Considering the upstream oil and gas industry, a continuous improvement safety model will be developed, with a specific case on the Norwegian North Sea. Best practice from lean manufacturing in the Automobile industry is taken as a benchmark.

1.7 Significance of the Study

The study is mainly framed to address workplace employee safety and injuries prevention using nonconventional methods in addition to the conventional safety management system: safety policies, regulations, plans, procedures, supervision, reporting, monitoring, etc. Lean thinking creates employees' value by creating a safe working environment to achieve competitiveness in the Oil and Gas industry with a special focus on upstream offshore activity in the North Sea.

Competitiveness and safe working environment from the perspective of process waste elimination, workplace safety, injury prevention, less impact on the environment, employees' value, customer value innovation, employee engagement and involvement, and communication for oil and gas industry upstream sector safe working environment in particular and global sustainability role in general.

Taking into account the complex supply chain, cyclic price and demand volatility of oil and gas, and the contribution and role of oil and gas upstream companies, taking into account these company's role in being part of a solution for reducing workplace injuries, global warming, and climate change are emphasized.

The agenda of safety and sustainability is a global agenda and everywhere now. Arguably, the oil and gas industry has high media exposure, and any major accidents are breaking news. Public awareness of the industry's activity is very high, and any major accidents impact the industry's license to operate in future projects. Thus, the oil and gas upstream sector needs to streamline its efforts in economic, social, safety, and

environmental terms so that the sector could be competitive and sustainable, to be a reliable future source of energy with minimal impact on the environment, workforce and getting the consent of the public and acquiring a permit to operate.

1.8 Expected Outcomes of the Study

The expected outcome of the research is mainly based on literature review, primary and secondary data collected, industry standards and best practices, and field observation analysis of the collected secondary data. The research work is fundamentally framed to match the set general and specific objectives and would answer the research questions. Some of the foreseen outcomes expected at the end of the research work would be:

- Review the safety system and personnel injuries in the upstream oil and gas industry, focusing on the North Sea upstream sector.
- Contextual assessment of continuous improvement methodology for upstream oil and gas sector as it applies for safety system.
- Identification of frequently happening injury type.
- Impact assessment of lean waste elimination, workplace safety, engaged workforce and communication clarity, and environmental performance in oil and gas industry competitiveness and creating a safe working environment.
- Analysis of lean thinking ‘respect for people’ and upstream workplace people-based safety systems parallels.
- Safety system model development for upstream oil and gas safety practices.

Chapter Two

2. Literature Review

2.1 Introduction

An oil spill in Brazil, a sabotaged pipeline in Nigeria, a chemicals processing plant explosion in Thailand, a blowout and disastrous accident in the Gulf of Mexico, Attwood et al., (2006); Bain & Company, (2013); Azadegan et al., (2013), the list could go on and on, where some of the big accidents the oil and gas industry confronted with. People may associate the operation of the oil and gas industry as the most polluting industry and sector with the most hazardous activities. There may be some truth in this thinking because the consequence of mismanagement and operations incidents could lead to catastrophic accidents on people, assets, and severe environmental damage.

The current body of knowledge practice is to base safety systems on compliance. Accident analyses and investigations regularly identify a lack of coordination among the players involved as a central contributing factor to workplace accidents (Dahl & Olsen, 2013).

This does not mean that the industry is not having the best safety and risk management techniques. For that matter, the industry has been transformed through technology development, big data, skilled workforces, and experts' contributions. With the current global energy supply status, the oil and gas industry has an indispensable role in the global energy supply. Inefficiency, accidents, incidents, near misses, and non-value-adding activities caused by safety-related issues are discussed in this study. The industry needs to innovate and continuously improve the value chain processes to add value from the perspectives of customers and employees (internal customers) and create a safe working environment.

There are some recurrent issues the industry needs to address for being better positioned in the global energy supply: The key problem areas the industry needs to address sooner than later are: Ineffectiveness, inefficiency, inflated cost, improperly used skilled workforce, high environmental footprint, disorganized supply chain, less engaged employee, unsustainable capital expenditure, high risk and hazardous working condition, minor to major personnel injuries, with minor injuries with high frequencies (Yang et al., 2011).

The global oil and gas industry is engaged in every day operation of drilling, developing, and producing tens of thousands of wells, hundreds of thousands of miles of pipelines, and millions of items of processing equipment to deliver energy to our homes, transport systems, businesses, and communities, (Bain & Company, 2013).

Some of the major challenges and opportunities the oil and gas industry is currently facing are:

- Recurrent minor to major injuries
- Volatile energy market on the macro-economic front.
- Increased operational and logistical challenges from a tougher environment.
- Increased regulatory pressure on the industry.
- Skills and workforce supply shortage in the industry.
- Competition from other energy sources

Opportunities:

- Growing markets in the low carbon sector of the economy.
- Room for innovating customer value and innovation of working environment safety practices.
- If the sector learns to see problems in processes, there is a high possibility for continuous improvement.
- Close collaboration between contractors, operators, the supply chain, and other partners.

Source: (The Global Oil and gas Industry: Prospects & Challenges in the next decades, 2012)

The oil and gas industry might have managed to tackle various challenges using the conventional way of doing things in the past. In the current market environment, business, as usual, would not take the industry up to the speed the global energy markets demand. As the pace of change accelerates in the 21st Century because of technological

opportunities, liberalization of world markets, and demands for innovation, quality, and speed, the oil and gas industry has to readjust and realign its operations to counter all these challenges (Yasar F.Jarrar & Mohamed Zairi, 2007).

This dissertation makes use of the parallels between lean management respect for people and an employee-based safety system. Anvari et al. (2011) argue that safer working conditions in which workers can find all the fire extinguishers; eye wash stations are accessible; slip, trip, and fall hazards are reduced; better organization reduces associate travel time and distance, thus reducing the chances for accidents could be produced using the lean management 6S techniques.

5S: 5S (Sort, Set in order, Sweep, Standardize, Sustain) is a workplace organization tool that improves worker efficiency by organizing the contents of the work area and standardizing work procedures; it is a method of creating a self-sustaining culture that perpetuates an organized, clean and efficient workplace, (Anvari et al., 2011; Jiménez et al., 2019; Sukdeo, 2017).

Lean management has been viewed as a practical approach for reducing the occurrence of non-value or destructive activities, such as wasting resources and safety-related accidents (Wu et al., 2019).

2.2 History of lean

Taichi Ohno's Toyota Production System (TPS) has been the research topic for both academia and practitioners. The book "The machine that changed the world" (James Womack et al., 1990; Spagnol et al., 2013) has well introduced to the world of the manufacturing industry the philosophy of the Toyota Production System (TPS). The automotive industry has undergone a dramatic transformation from craft and mass production to the contemporary development of lean production. Lean is a paradigm shift in mindset and a continuous improvement philosophy and thinking where it has acquired popularity even beyond the manufacturing industry, such as healthcare (Demeter & Matyusz, 2011).

Today's oil and gas industry resembles the past automotive production system (Sakhardande, (2011). Sakhardande (2011) emphasizes that Lean management has the potential to benefit the oil and gas industry supply chain. The core pillar of lean philosophy, 'respect for people,' focuses on the creative potential of the workforce,

considering the workforce as the doer of the task at hand and, at the same time, the best placed to suggest continuous improvement ideas, with respect to job improvement and workplace safety.

The Toyota Production System that helped Toyota survive the company's financial crises after WWII was coined lean production by MIT researchers Womack et al. (1990). The Toyota production system has given the company to win the fierce competition through process waste elimination and solving defects and problems at the source.

Some of the chronological development in lean production:

- Henry Ford, Ford Motor Company, 1910, Continuous System.
- In the 1950s, Taiichi Ohno, the Toyota Production System.
- “The Machine that Changed the World,” Womack et al., (1990).
- “Lean Thinking,” Womack & Jones, 1996.
- “Learning to see,” Shook & Rother, 1998.
- “Toyota way,” Liker, 2004.
- To date, the lean thinking philosophy has gained popularity and is being implemented in industries other than manufacturing and healthcare (Riezebos & Klingenberg, 2009).

The research done by MIT researchers through International Motor Vehicle Program (IMVP) found out that the competitive advantage to the Japanese automakers, mainly Toyota, was attributed to the lower amount of in-process inventory, company culture emphasizing teamwork, clarity in communication, seeing problems and solving them, continuous improvement and management practice (Kraficik, 1988; Liker, 2004; Womack et al., 1990)

The term lean was first coined by MIT researchers. Still, the very idea and philosophy it explains were stated by different terms such as Just-in-time production Schonberger, (1982), World Class Manufacturing Schonberger, (1986); Langstrand, (2012), and Toyota production system (Ohno, 1988; Shingo, 1984).

During the early 1900s, Henry Ford and Frederick Taylor developed a new production system called “scientific,” establishing various principles, tools, and methodologies Dieste & Panizzolo, (2019). However, the scientific method went into crisis in the 1970s when other manufacturers could provide much higher model variability (Panizzolo, 1998). In this context, the Toyota Production System (TPS) developed by Taiichi Ohno was created. Due to the latest technologies, that new paradigm could synchronize the production and assembly of components in a single International production line (Ohno, 1988). Currently, the lean production system is the most extended production paradigm Womack and Jones, (1996). Its practices reduce non-value-added activities in the entire firm processes, identifying seven types of waste, also known as Muda Ohno (1988).

This philosophy is founded on “doing more with less” (Womack and Jones, 1996). From the waste identification process, the employees can understand which operations add value, which do not, and which do not and contribute to waste. The lean paradigm is a multidimensional concept characterized by several practices to accomplish waste reduction and value delivery objectives (Dieste, M et al., 2020).

2.3 Lean Principles

James Womack & Dan Jones 1996 published their book – ‘Lean Thinking: Banish Waste and Create Wealth in Your Corporation.’ In this book, the authors formulated the Five Principles of Lean framework for lean implementation. These are:

- Specify value from the customers’ perspective,
- Map the value stream to understand the value and non-value-added steps
- Flow the work through the processes in the value stream
- Schedule the work based on customer pull
- Strive for perfection through continuous improvement and waste elimination

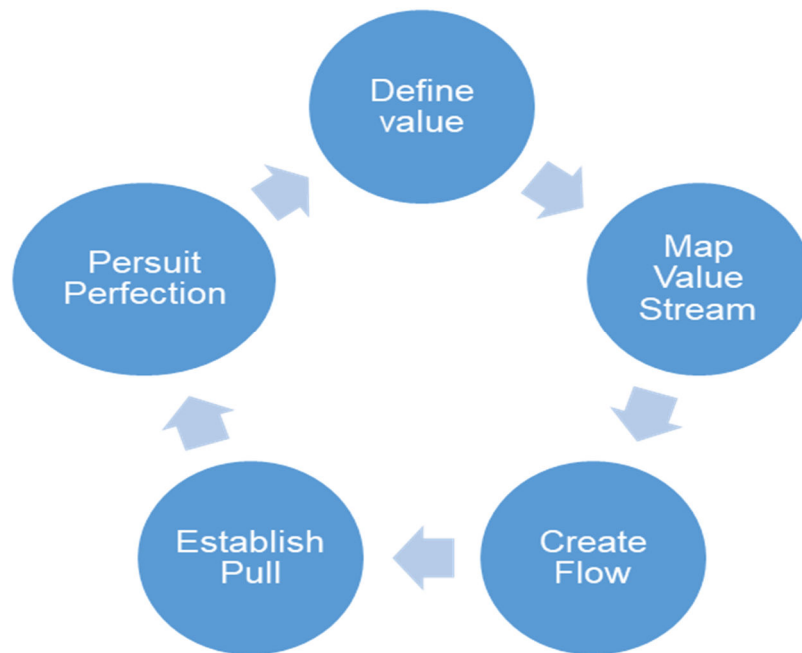


Figure 2. 1 The five key principles of lean (Womack and Jones, 1996; Kilpatrick, 2003; Emiliani, 2004; Poppendieck, 2011)

Lean has its philosophy, principles, and tools like any other methodology. Lean has two philosophies, five principles, and various tools. It is imperative not to be taken away just by the tools just focusing on the ‘toolboxes’ without having the thinking and the culture of continuous improvement governing the organization's day-to-day working culture.

Firms must have a knowledge management culture and follow one of the lean philosophy's core pillars: ‘respect for people.’ One of the common cultures of a lean company is its organization-level learning culture. Regarding the idea of the learning organization, the work of Senge could be the prominent one. Senge (1990) argues that all companies should possess the characteristic of a learning organization to achieve continuous success. According to Senge, a learning organization can be achieved by practicing five disciplines: a shared vision, personal mastery, strong mental models, group learning, and system thinking (Senge, 1990; 1991).

Various practitioners and academia have contributed to lean practice, tools, and principles. Table 2.1 below depicts the practices of some authors.

Table 2.1 various lean practices and names of authors

Lean practices	contributor
Total quality management	Eswaramoorthi et al., (2011), Wong et al., (2009), Sahoo et al., (2008), Abdulmalak and Rajgopal, (2007), Shah & Ward (2002)
Pull system (Kanban)	Singh et al.,(2011), Nordin et al., (2010), Singh & Sharma(2009), Wong et al., (2009), Arashpour et al., (2009)
Preventive Maintenance	Nordin et al.,(2010), Abdulmalek & Rajgopal (2007), Shah & Ward(2002), Cua et al(2001), Feld(2000)
JIT	Eswaramoorthi et al.,(2011), Nordin et al(2010), Wong et al(2009), Arashpour et al(2009), Sahoo et al(2008)
Cycle Time Reduction	Singh et al.,(2011), Shah & Ward (2002), Flynn et al(1999), White et al(1999), Sakakibara et al(1997)
Cross-Functional Team	Eswaramoorthi et al., (2011), Nordin et al., (2010), Shah & Ward (2007), Bonavia & Marin (2006), Shah & Ward (2002)
Continuous improvement	Singh et al. (2011), Sahoo et al. (2008), Abdullah(2003), Shah & Ward(2002), Flynn et al. (1999)
Single Piece Flow	Eswaramoorthi et al.,(2011), Arashpour et al(2009), Singh & Sharma(2009), Wong et al(2009), Pavnaskar & Gershenson(2003)
Zero defects	Singh et al. (2011), Abdullah(2003), Karlsson et al. (1996)
Value Stream Mapping (VSM)	Eswaramoorthi et al., (2011), Shook & Rother (1998), Singh et al., (2011), Singh & Sharma (2009), Wong et al., (2009), Sahoo et al., (2008), Womack and Jones, 1996

Inventory management	Singh & Sharma (2009), Pavnaskar & Gershenson (2003), Russell & Taylor (1999)
Poka-Yoke/ Error proofing	Eswaramoorthi et al(2011), Nordin et al(2010), Singh & Sharma(2009), Wong et al(2009), Arashpour et al(2009)
Standard work	Eswaramoorthi et al., (2011), Singh & Sharma (2009), Wong et al., (2009), Abdullah (2003), Pavnaskar & Gershenson(2003), Russell & Taylor(1999)
Kaizen	Eswaramoorthi et al.,(2011), Singh et al(2011), Nordin et al(2010), Singh & Sharma(2009), Wong et al.,(2009)
Heijunka/ Production smoothing	Eswaramoorthi et al.,(2011), Wong et al(2009), Arashpour et al.,(2009), Sahoo et al(2008), Abdulmalek & Rajgopal(2007)
5S	Eswaramoorthi et al.,(2011), Arashpour et al(2009), Sahoo et al.,(2008)
Visual management	Eswaramoorthi et al.,(2011), Nordin et al(2010), Singh & Sharma(2009), Bonavia & Marin(2006)
Jidoka	Eswaramoorthi et al.,(2011), Wong et al.,(2009), Arashpour et al.,(2009)
Andon	Eswaramoorthi et al.,(2011), Wong et al(2009), Arashpour et al.,(2009)
Takt Time	Eswaramoorthi et al.,(2011), Singh et al(2011), Pattanaik & Sharma(2009), Singh & Sharma(2009), Alvarez et al.,(2009)

Adapted from (Dhankhar et al., 2014)

2.3.1 Customer Value

One of the basic principles of lean is waste elimination and value creation, the value from the customer perspective, Womack & Jones, (1996; Dickson et al., (2009). The global market environment is characterized by the emerging trend of demanding customers, global competition, and slow-growth economies and industries (Woodruff, 1997).

Organizations continuously search for factors that could position them strategically for winning the competition. Usually, they do an internal and external market assessment, using tools such as SWOT analysis, to align their strategy to capitalize on their strength and seize the external opportunities. Many organizations search for new ways to achieve and retain a competitive advantage. Presently, a major source of competitive advantage likely will come from a more outward orientation, by having the opinion of the customer in the company's value proposition taking into account customers' perspective, Woodruff, (1997). The internal employees' values that could be expressed in a safe working environment and respect for employees are competitive advantages that could equally place the firm in a strategic position combined with the external customer value.

Two of the key concepts in lean are value and waste Womack & Jones, (1996); Pavnaskar et al., (2003); Ohno, (1988). The main goal of lean is to eliminate any activity and processes that do not add value to the customer. Value is the starting point of lean and is defined by the ultimate customer Womack & Jones, (1996). Lean emphasizes reducing and eliminating waste (Benders & van Bijsterveld, 2000; Browning & Heath, 2009; Stone, 2012).

Saunders & Preston (1994) and Dalu & Deshmukh (2002) regard waste as an outcome of a process where prerequisites are not fulfilled. The elimination of waste increases customer value and employees' value by optimizing the use of resources and creating a safe working environment Womack and Jones, (1996); Narasimhan et al., (2006); Dickson et al., (2009). A stronger customer perspective is commonly a principal aim of Lean production (Hines et al., 2004; Liker & Meier, 2006; Womack & Jones, 1996). Fig 2.2 below depicts the customer value model proposed by (Van der Haar et al., 2001).

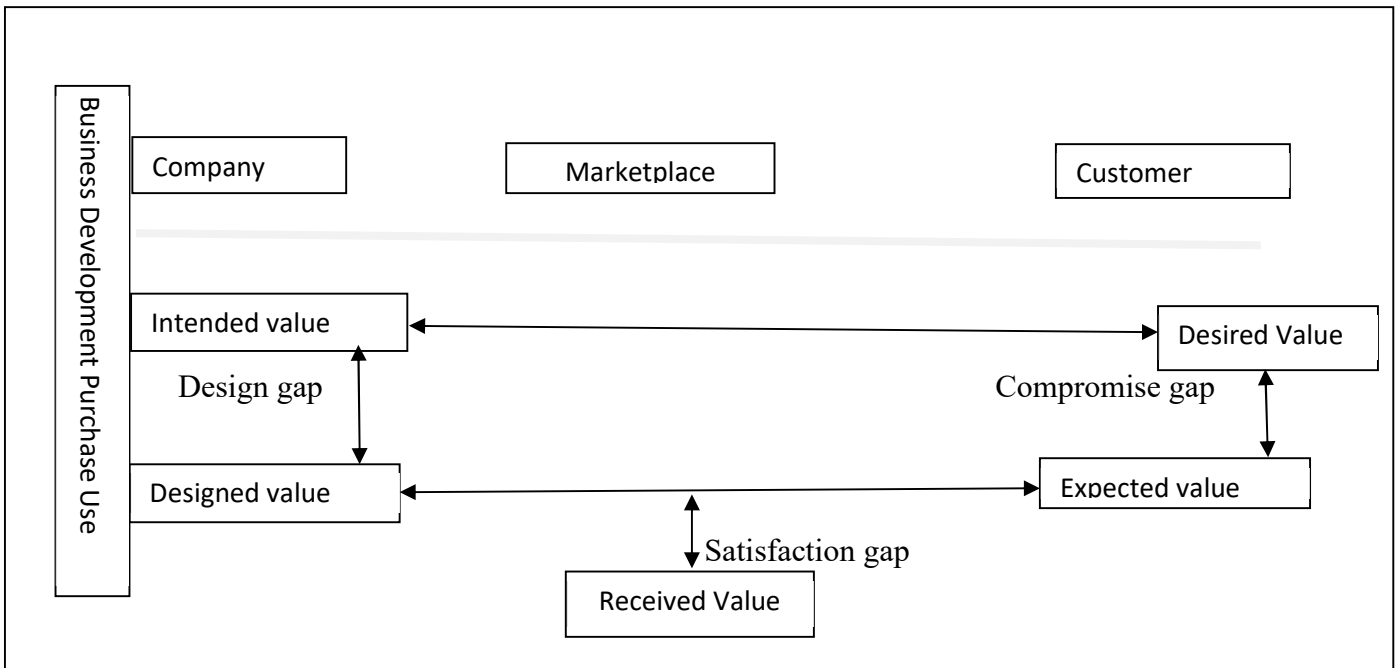


Figure 2.2 the customer value model (Van der Haar et al., 2001)

A common trend in a lean community is to search for value proposition gaps (the difference between designed value and value expected by the customer). It is customary by lean practitioners to say, ‘No problem is a problem’ lean practitioners ‘love’ problems. Problems could be hidden or visible. Problem areas are where the improvement effort must apply on. In a lean community, it is a common practice to equate problems to a gap. Unseen hidden problems in process flow could be the primary source of workplace hazards that need to be identified, controlled, and eliminated.

As one of the lean philosophy pillars, ‘respect for people’ employees are not there to do the job but to solve and improve and fix broken processes and unsafe conditions and control and eliminate hazardous conditions. As the frontline employees are the ones who have day-to-day contact with the process and who have expertise in the process function. Thus, the frontline employees need to be coached and mentored by supervisors and middle-line managers to develop practical problem-solving capabilities and ‘learning to see problems.

2.3.1.1 Value in Oil & Gas Lean context

Too much waste, redundancy, and lengthy turnaround times result in even the most efficient oil and gas companies failing to meet customer expectations 25-50% of the

time (Resta et al., 2015; www.cwcschool.com). With the current low crude price and shrinking margin, every penny lost due to inefficiency and non-value-adding activities costs the sector a lot. Moreover, in every inefficient and broken process and activity, hidden and underlying hazards could cost the sector more when expressed in accidents, incidents, and injuries.

Lean can be applied to the overall process (lifecycle) of the oil and gas industry:

- Upstream process
- Midstream process
- Downstream
- Management processes, (www.cwcschool.com; Resta et al., 2015)

The fall in oil prices has exposed an inflated cost base in many oil and gas companies, forcing them to reduce operating costs, rationalize investment budgets, and boost operational efficiency, John de Wardt, (2016); van Dun et al., (2016). The economic downturn exposed the trend of the inflated cost structure and investment. The low oil and gas price could allow the industry to control cost structure, optimize and streamline processes, eliminate non-value-adding activities, and reduce injuries to personnel by keeping the workplace tidy and clean.

Automation could control and reduce hazardous conditions, which otherwise expose employees to high risk during manual work. One of the common automation mistakes is to mechanize a broken system. Process wastes and processes activities do not add value from the perspective of the customer need and employee safety to be streamlined before any automation efforts. Arguably, it is the broken process to blame for poor quality and below-standard products and services, not the workforce. Improved work processes would be sources of employee engagement, respect for employees, and a safe working environment.

2.3.1.2 Value chain in upstream oil and gas

Porter (1985) introduced value chain analysis as a generic business management tool. Numerous contributions to value chain analysis and value networks have been published by authors, such as Allee (2003), Weijermars (2008), Weijermars (2010), and Holweg (2007). Industry stakeholders commonly benefit from a systemic value network

analysis because it identifies key areas in the value network where constraints occur and opportunities for improvements arise. The global oil & gas industry is under considerable pressure to meet the world's demand for affordable and secure energy supply, Armaroli & Balzani, (2006). Environmental concerns have intensified the inter-fuel competition, and this battle can be prolonged in favor of optimum utility for the remaining global oil and gas reserves.

Lean thinking applies value chain analysis concerning customer value and employees' value. Value stream mapping is a popular lean tool that helps create a customer value stream map. The non-value-adding activities and processes are identified and eliminated using optimized processes (Rother & Shook, 1998).

2.3.1.3 Waste in Upstream Oil and Gas context

Process Waste makes organizations less able to achieve their objectives; this, in one way or another, leads to using limited resources in ways that do not contribute to the organization's overall goals. This study argues safety-related issues could be considered as the ninth lean waste as safety incidents, accidents, and time wasted due to accidents and damage done to people and asset is a huge waste that needs to be addressed by the oil and gas industry. Lean is a philosophy that involves all levels of the workforce and management. Creating Value from the customer perspective and waste elimination is the core of lean methodology. One-way lean organizations strive toward perfection is by remaining constantly aware of waste so it can be avoided or eliminated (Womack et al., 1990).

Lean philosophy identifies eight sources of waste that detract from the value a customer receives from a business process. Educating employees about the eight sources of waste and conducting team-based reviews of business processes to look for and correct them can yield substantial benefits (Kavanagh & Krings, 2011; Ohno, 1988).

'Quality at the source' needs to be the culture of every frontline worker through the mindset of the problem-solving and continuous improvement process. As the oil and gas industry is currently struggling to cope with aging workforce, the industry needs a knowledge management system more than ever to perform technology transfer between the senior experienced and the junior workforce, Montano et al., (2001). Industrial 'Muda' elimination is a major challenge that the experts face in the day-to-day activities of production systems (Arunagiria & Gnanavelbabub, 2014).

Inflated cost structure has been hiding process wastes in oil and gas upstream sector similar to overflowing river hides obstacles and stones could easily result in the effect of ‘tip of the iceberg ’ where the improvement processes may focus on the one easily seen on the ‘surface ‘ without tackling the root causes.

2.3.1.4 Identifying waste

The elimination of waste is the primary goal of any lean system, Womack et al., (1990). In effect, lean declares war on waste – any waste. The issue of waste is a cornerstone of the Lean philosophy Pienkowski, (2014). Waste or Muda is anything that does not have value or does not add value. Waste is something the customer will not pay for, Rother & Shook, (1998). Learning to see and spot waste is key and then stop waste. There are two types of waste: obvious wastes and hidden wastes. Uncovering and eliminating the latter is important since they are usually bigger. Waste can be in the form of unnecessary output, input, or processing Schulze & Stormer, (2012). It can include materials, stocks, equipment, facilities, and person-hours, utilities, lost time injury, documents, expenses, motion, and other activities that do not add value. The steps to effective waste elimination are:

- ✓ Make waste visible.
- ✓ Be conscious of the waste.
- ✓ Be accountable for the waste.
- ✓ Measure the waste.
- ✓ Eliminate or reduce the waste; source: (rtdonline.com)

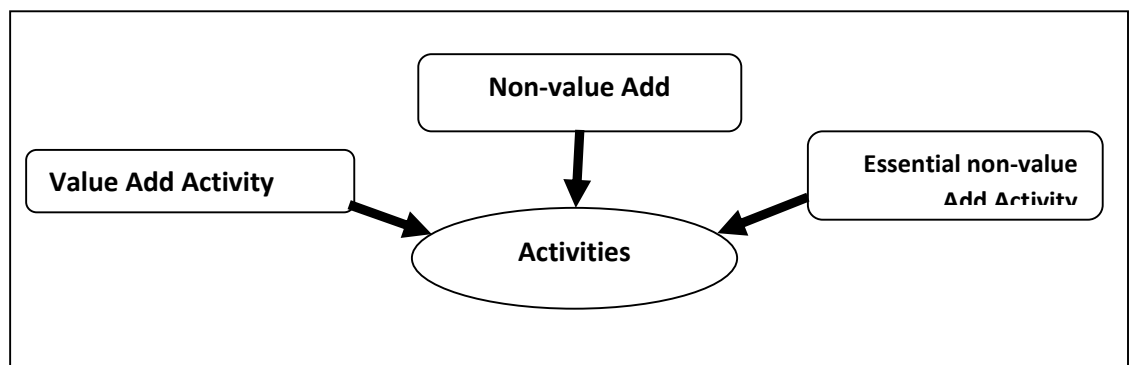


Figure 2.3 Categorization of activities (Benson & Kulkarni, 2011)

Fig. 2.3 illustrates the classification of process activities and their association to waste. The focus of lean practice is to identify the non-value-adding activities and eliminate them from the process activities. This does not mean that every non-value-adding

activity could be eliminated. Typical examples are the essential non-value-adding activities.

2.3.1.5 Waste in upstream oil and gas processes

Continuous improvement, a process for relentless waste elimination, involves all levels of employees working together to streamline work and reduce non-value-added activities and constantly evolves to proactively address general marketplace conditions as well as individual steps in the production process, Mastellari & Renegar, (2015); Schulze & Stormer, (2012). Continuous improvement has long been an essential part of the Lean philosophy. Still, Mastellari & Renegar (2015) assert that lean philosophy has not been as effectively and consistently applied in the oil and gas industry as it could be, thus not achieving the positive impact experienced in other industries, such as healthcare and auto industries.

Oil and gas companies are now more global, and some are becoming more process-based. Cross-functional stakeholders are increasingly demanding results that are more difficult to achieve given the ongoing economic uncertainty and challenging market conditions; the industry has been challenged by EYGM Limited (2013); Lopez et al., (2015). The long-term low oil price coupled with expensive upstream offshore developments, high capital and operating costs for deep-water wells offshore, and unconventional resources such as oil sands and horizontal drilling techniques compound the industry's cost challenge. That's where performance improvement comes in, EYGM Limited, (2013); Bamber et al., (2014)). Performance improvement is an operational philosophy of management that can benefit customers, shareholders, employees, and suppliers. Companies facing capital and operational cost constraints within the oil and gas sector are employing performance improvement programs and tools to help drive down costs and improve their bottom line (Pampanelli et al., 2014; EYGM Limited, 2013).

Lean philosophy would be an ideal performance improvement practice and methodology. This dissertation recommends focusing on customer and employees' value by eliminating non-value-adding activities from the oil and gas processes. This could lead to better customer value, company profit, a happy and engaged workforce, and a safe working environment.

2.3.2 Value Stream

One of the fundamental principles of lean is to identify the value stream, Womack and Jones, (1996). Analyzing the value stream is an essential part of a lean principle that enables identifying product groups and processes to map the value stream Rother & Shook, (1998). By walking the value stream at the ‘Gemba,’ at the place where the real work is done, and noting the work time (value-added time) and the non-valued-added time, possible to generate a visual map of processes and activities and be able to see areas for continuous improvement, hidden problems, bottlenecks, workplace safety hazards (Dickson et al., 2009). The primary purpose of a value stream is to identify processes and activities that do not add value to the customer and employees at large. Eliminating these processes and activities could result in faster throughput, higher quality, reduced inventory, customer value, and increased employee safety.

One purpose of walking the value stream is to identify wastes; waste (Muda) could be expressed in the ‘Eight Wastes+’; Shigeo Shingo: the author of this study, proposes safety incidents as one waste that could be added to already existing eight wastes.

- ✓ Waste of overproduction – produce only what is required. Overproducing creates unnecessary inventory. Overproduction is the leading cause of most other wastes.
- ✓ Waste of waiting – waiting for the availability of materials or other resources and inputs.
- ✓ Waste of transportation – The longer transportation of finished and unfinished materials takes, the more time is spent without gaining money (value), and capital could be tied- up and lead to extra cost.
- ✓ Waste of over-processing- Processing beyond the standard required by the customer, work above and beyond specification.
- ✓ Inventory – Too much inventory is useless as the cost of carrying inventory increases.
- ✓ Waste of motion – Waste of motion occurs when individuals move more than is necessary for the process to be completed.

- ✓ Defects – A defect is a component the customer would deem unacceptable to pass the quality standard; rectifying defects costs money concerning time, effort, and materials.
- ✓ The unused workforce talent-the most valuable asset an organization has is its workforce. Unable to use these valuable resources is a significant source of waste.
- ✓ Workplace accidents, incidents, near misses, and injuries are causes of damage to people and assets. On top of that, unwanted costs and wastes that do not add value to the customers endanger the employees' safe working conditions and threaten the company's reputation. Moreover, productive production time could be wasted during a time out for safety concerning incidents in the form of an investigation.

2.3.2.1 Value Streaming in Upstream Oil and Gas

The oil and gas sector operates in an environment of unprecedented opportunity and challenge, changing from time to time, with high volatility and risk. The industry has grown strongly over the past decades. Its outlook is equally positive, driven by three central economic and demographic drivers of demand (somewhat fluctuating population growth, global GDP growth, and rising energy consumption, which depend on global economic activity). Source: (ExxonMobil” The outlook for energy, A view to 2040; BP” Economic outlook 2030; US energy information administration (EIA); PWC, 2013).

In the oil and gas value chain, value stream partners need to collaborate to facilitate the value chain supply visibility, resolve any bottleneck and restriction to value stream flow along the chain, and see and eliminate process wastes that do not add value for the end-user.

From time to time, the rare catastrophic accidents in the industry rock industry to its core. Before an incident grows into a big devastating accident, it could connect small near misses and minor incidents before it grows into a catastrophic accident. The focus of this research is on small and minor incidents and injuries. Preventing the small ones would be manageable, cost-effective, and could be done at the frontline with the responsibility of every employee.

Even if it is customary to learn from accidents, incidents, and near misses, the industry has much to learn from the best performance in its safety system development. The author of this study argues that a safety system, like any system, needs continuous improvement, learning from experiences, and using the input and involvement of every workforce.

2.3.3 Create Flow

Creating continuous flow means letting products flow through the process rather than producing in batches that are moved between process steps Womack and Jones, (1996), with no idling time between work activities Liker & Meier, (2006). In order to achieve a flow-based production, the boundaries between functions, departments, supplier tiers, and professional groups must be minimized Ohno, (1988); Womack and Jones, (1996). Flow is how work moves through a system. When a system is working well or has a “good” flow, it tends to move steadily and predictably, whereas a “bad” flow means the work starts and stops, Womack & Jones (1996); Lim (2008); Bashir et al., (2011); kettering.edu, (2016). When there is an interruption in the flow, there is a high possibility that it would create process waste. Mike Wroblewski (2016); kettering.edu, 2016) identified some flows of manufacturing: the flow of raw material, the flow of work-in-process, the flow of finished goods, and the flow of information.

In oil and gas operations, activities flow could be restricted in terms of waiting, which could happen in the form of waiting on weather that is a common occurrence in the North Sea harsh environment. The oil and gas industry generally has a complex supply chain, particularly offshore oil & gas. Supplying to remote offshore locations during the year’s harsh weather season would be challenging, resulting in flow restrictions.

Restricted process flow could be a potential trap for inefficiency and workplace hazards. The right to stop unsafe tasks and the access to seek help from an immediate supervisor when a process stop working using the ‘Andon’ system could facilitate resolving the problem at the source and empower employees to exercise the right to stop unsafe acts and conditions.

2.3.4 Establish Pull

Pull means that goods or services only are produced when the internal or external customer needs them Womack & Jones, (1996). "Push type" means Make- to -Stock in

which the production is not based on actual demand. "Pull type" means Make –To-Order in which the production is based on actual demand.

There are three basic types of pull systems; replenishment pull, sequential pull, and mixed pull system, which combine elements of the previous two. In all three cases, the important technical elements for systems to succeed are:

- ✓ Flowing product in small batches (approaching one-piece flow where possible)
- ✓ Pacing the processes to Takt time (to stop overproduction)
- ✓ Signaling replenishment via a Kanban signal
- ✓ Leveling of product mix and quantity over time (www.lean.org)

The concept of pull in Lean production means responding to customers' pull or needs, Saurin & Ferreira, (2009). Lean organizations design their operations to respond more to their customers' varied and changing needs. A more continuous flow results in items being moved immediately from one workstation to the next as soon as they are ready for the next process (www.lean.org).

Typical inventory in the upstream oil and gas sector includes:

- ✓ Drill pipes
- ✓ Drill collars
- ✓ Heavy-weight drill collars
- ✓ Drill bits (varies for different hole sizes)
- ✓ Cement
- ✓ Chemicals including:
 - Corrosion inhibitors
 - Weighting agents (barite)
 - Surfactants
 - Lubricants
 - Emulsifiers
- ✓ Casing strings

- ✓ Spare parts for power systems equipment

A pull system could be a very effective system in the upstream oil industry to organize the flow of material and equipment to the right place at the right time, thereby reducing the wait time for the machinery and equipment to arrive at the remote location on time, safely and within allocated budget (Agarwal et al., 2016).

In a lean, pull system, tasks given to the workforce are pull-based, where jobs are leveled to avoid employee overload and prevent stress and personnel safety issues related to the overloaded task push system.

2.3.5 Strive for Perfection

Womack & Jones (1996) suggest that the lean principle should be seen as an iterative process leading to perfection. Lean thinking presents principles and tools to eliminate waste and strive for perfection through continuous improvement, Holtskog, (2013). The concept of perfection in lean management means endless opportunities for improvement, perfection will never be achieved, and its pursuit is a goal worth striving for because it gives continuous improvement (Emiliani, 1998).

Womack & Jones (1996), managers need to learn to see value being pulled by the customer at every step. The final form of seeing value being pulled is to bring perfection into a clear view, so the objective of improvement is visible and real to the whole enterprise. In addition to forming a picture of perfection with the appropriate thinking and practices, enterprises must set a strict timetable for steps along the path.

The high-achieving organizations set specific timetables to accomplish impossible tasks and then routinely meet or exceed them. Continuous improvement is one of the two pillars of the Toyota Production System; seemingly slight but continuous improvement leads the organization to its true north values (Liker, 2004). Paul Aker's '2 Second Lean' (2016) is the best example of how daily improvement could bring a substantial competitive advantage to a company (Fastcap).

The sector's safety system needs to follow the principle of pursuit of perfection, building on its safety system's best achievements and learning from incidents, accidents, and near misses. Complacent about previous achievements is a trap, leading to stopping learning and an obstacle to continuous improvement. In some cases in the sector, a catastrophic accident happened after years of the best safety record. Thus, prior safety

achievements are not guaranteed for tomorrow's accomplishments; the industry must follow a continuous safety improvement system with 'perfection' in mind.

2.4 The human side of lean

Attempting to adopt lean is a challenge for many organizations, and the key to this implementation is the people and leaders in the organization, Manfredsson, (2016); Wackerbarth et al., (2015) Helmold, (2020). In the pursuit of increased profits and cost cuts, companies try to implement lean, using tools and methods, but disregard the lean system and, maybe, more importantly, the human side of lean, captured in principle "respect for people" Emiliani, (2011). Consequently, the humans in the system are forgotten or neglected. Womack, Jones & Roos (1990) asserted that to be positive within several areas, such as reducing stress, adding customer value, creating a safe and organized work environment, and enhancing employee engagement, the effects of lean implementation on an employee and team perspective are imperative.

A possible way to create positive employee effects is for management to secure positive effects on job autonomy, skill use, and participative decision in the lean implementation Parker, (2003). Because one in four technical professionals in oil and gas will retire in the next few years, this scarcity could become even more severe, Bain & Company (2013). It is widely asserted that employee participation may affect employee job satisfaction; employee productivity, safety, shared company culture, and employee commitment can create a comparative advantage for the organization (Bhatti & Qureshi, 2007; Bashin & Brucher, 2006).

2.4.1 The Toyota Way

The initial description of the Toyota Production System in English appears to be from the paper entitled "Toyota production system and Kanban system Materialization of just-in-time and respect-for-human system" by Sugimori et al. (1977). In 2001, the Toyota Motor Corporation published an internal document called "The Toyota Way 2001," which states the two objectives of "continuous improvement" and "respect for people" as top-level company principles.

Toyota's Production System (TPS) is based on lean principles, including a focus on the customer, continual improvement and quality through waste reduction, and tightly integrated upstream and downstream processes as part of a lean value chain. The lean

movement has gone beyond the shop floor to healthcare and is spreading to other service industries (Liker & Morgan, 2016; Ringen, 2014).

Fig 2.4 below depicts the two pillars of the Toyota way, continuous improvement and respect for people. Respect for people means developing the capability of the employees so that they do the job and, at the same time, improve it through scientific problem-solving. Moreover, suggesting ways of improving the process in a value add way and doing the job safely.

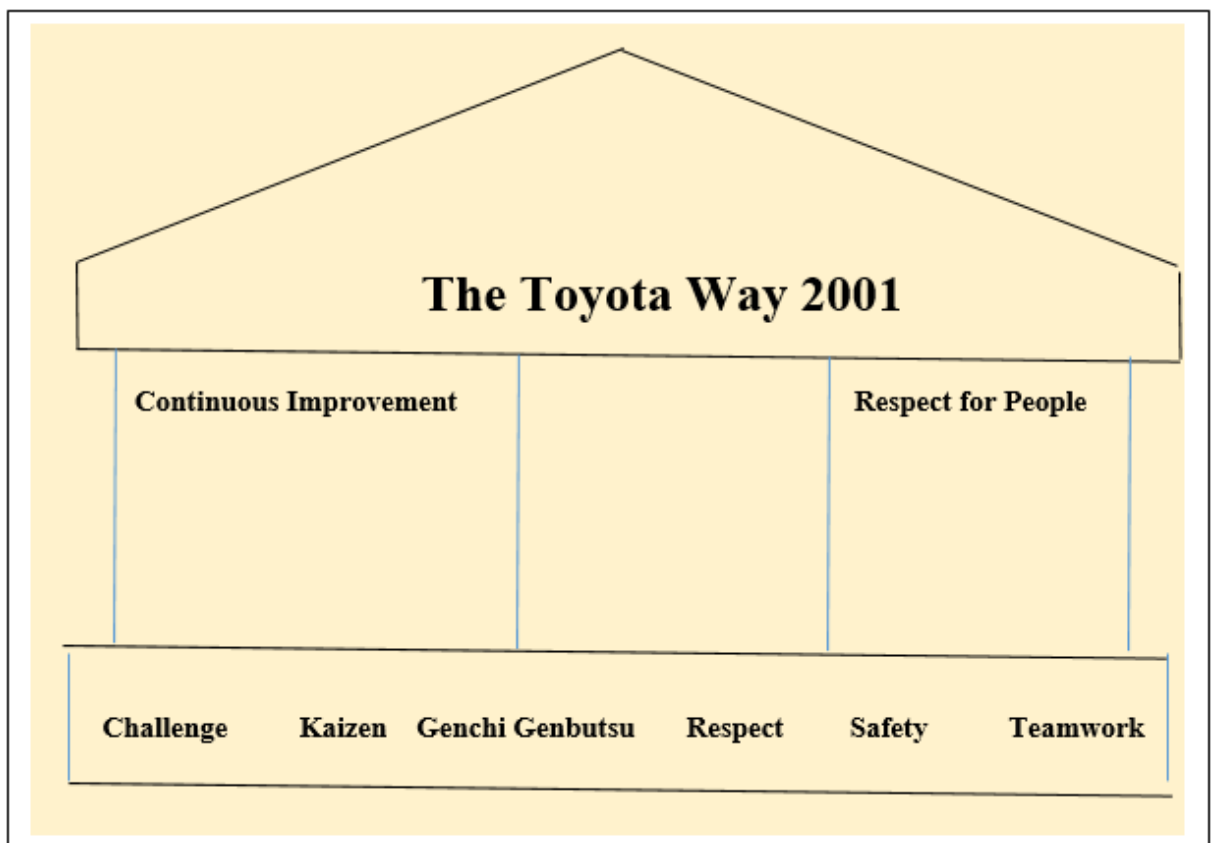


Figure 2. 4, the Toyota way, adapted from Liker (2004; Marksberry, 2011; Krijnen, 2007)

The tools of TPS were designed to highlight and identify problems within the organization. According to Liker (2004); Rother & Shook (1998), the key to success is having a production system that highlights problems and a human system that empowers people to identify and solve them and continuously improve the safety practice of the workplace.

Lean is not all about a bunch of toolboxes. The core of the lean philosophy is the lean thinking and culture that need shared understanding by all workforces and management

across the organization through problem-solving and continuous improvement. Companies that use only the “waste reduction tools” toolbox without embracing the underlying philosophy and culture are unlikely to gain more than limited and temporary results (Seddon & Caulkin, 2007; Hamdar et al., 2015).

2.5 Lean Safety and Sustainability in Upstream Oil and Gas

HSE and sustainability are becoming a global agenda in the existence of any business entity. On the current business norm, it is not enough to make a profit and grow the business; a sustainable business strategy that considers profitability and growth with a long-term agenda of sustainability and HSE measures is a competitive advantage and an action that could give a company license to operate.

Many assert the oil and gas industry has the highest environmental footprint and the most hazardous operations compared to other industries. This supposition has some truth, as the hydrocarbon produced by oil and gas companies has a greenhouse effect. However, the petroleum industry could be part of the solution in the fight against climatic change and global warming by applying clean technology and employing methodologies like lean thinking, enabling the industry to do ‘more with less.’

The author of this research strongly asserts that lean has a lot to offer for the competitive advantage of the oil and gas industry from the perspectives of sustainability and HSE measures by providing the global energy market with low cost and added customer value of petroleum products and safer working environment for employees. This is in line with the finding of Kurdve et al. (2014) that integrating environmental management, operational excellence, safety management, and sustainability management into everyday operations would promote environmentally friendly and green operations. Hafey, R (2017), emphasizes that lean and safety have always been interconnected.

2.6 Safety Communication

Communication relating to safety must flow freely through all levels of the organization. Safety-related communications must be clear and concise, and employees must understand their responsibilities. Explain why safety changes are needed. In addition, employees must be aware of the process to express a safety concern or to

communicate suggestions for improvement. A simple avenue for communication must be present, and employees must know whom to contact.

The purpose behind increased visualization is to communicate key information effectively to the workforce by posting various signs and labels around the workplace area Enshassi & Abu Zaiter, (2014). Awada et al. (2016) can extend visual management for safety.

Industrialization and the proliferation of the population have resulted in increased occupational injuries in the workplace. A safety incident does not happen by chance as it is an interplay between several organizational factors. Thus, safety participation is essential to raise employees' awareness of a safer workplace. Affermative and interactive safety communication, good upper management support in safety leadership, and positive safety culture should be practiced in organizations—these increase employees' willingness to participate in safety activities to ensure a safer workplace.

Workplace safety is a combined results of several factors, namely human behavior, organizational factors (such as supervision, work conditions and processes, planning, and organizational learning), and latent conditions such as the absence or dysfunctional nature of physical and functional barriers to prevent accidents, Hollnagel, (1999); Hollnagel, (2004). According to Ibrahim et al. (2012), a safer workplace should include safe premises and safety regulation enforcement and provide appropriate safety training. In this study, workplace safety is referred to as a working environment where all the workforces channel their efforts into mitigating perceived risk and hazardous activities.

Safety participation refers to an employee's intended involvement in safety-related activities, which add to the development of a safer working environment Griffin & Neal (2000). Besides, Griffin & Hu (2013) has designated safety participation as a behavior for creating a safety-supportive working environment. Measurement of safety participation is imperative to measure the current status of the workforce's practice to the safety system and understand the safety culture.

Safety communication refers to how well safety issues are communicated in the working environment Brondino et al., (2012). In efforts among the industries to remain

vibrant and competitive, workers' safety has often been overlooked by employers and sometimes even by the employees themselves, Dubey, (2015). To create a safer workplace, strong employee safety involvement is required Neal, (2000); Griffin & Neal, (2000); Christian et al., (2009). Safety activities such as safety meetings, safety decision-making, and safety training require a high level of employee engagement and involvement to promote efficiency (Subramaniam et al., (2016); Nielsen & Randall, (2012). A low level of safety involvement will affect business productivity and performance as the workforce does not feel safe during their work (Khairiah, 2008).

An accident does not happen by chance but is an interaction of several factors such as employees, devices, working practices, etc., Mohamed & Ideris, (2012); Arquillos & Romero, 2016).

Various researchers have been researching to explore safety communication and its effects on workplace safety Kim et al., (2008); Lijie et al., (2012); Kaskutas et al., (2013); Siew, (2015). Safety-relevant communication supplies information and understandings related to a business's operation to the organization's members, which in turn enhances knowledge of how to work safely (Sadus, 2007).

2.7 Employee-based safety system

Alignment and synergy between lean and safety management areas are expected because all near misses and injury incidents represent waste from the lean perspective. Lean principles and practices can provide a valuable opportunity to improve worker safety further (Gambatese et al., 2017).

Accidents and employee injuries result in added time to clean up after the incident, repair damaged work, and attend to the injured employees, all of which represent waste. Previous studies have identified that some lean practices positively impact safety management practices, and collaboration between lean practitioners and safety professionals is needed to implement more reliable safety controls (Gambatese et al., (2017).

Both lean and safety should have the common goal of reducing accidents and hazards. If lean and safety issues are addressed simultaneously, the result is a more productive and safe working environment (Cudney et al., 2015).

Lean has been hardly implemented in oil and gas. Applying lean to safety management efforts is a promising research area and has been discussed widely in the construction community. Some researchers assert that reducing occupational hazards is a naturally occurring effect of implementing lean practices. Lean focuses on reducing waste, and poor safety can be considered a source of waste. Typical lean production tools include error proofing, 5S, standardization, and the most common safety management practices such as planning and staffing for safety (Antillon, 2010).

Gambetese & Pestana (2014) assessed the extent to which lean practices impact workplace safety risk and support commonly-implemented safety practices. The researchers found that:

- Improving production through applying lean principles naturally leads to enhanced worker safety. Utilizing lean practices provides the ability to “make safety better.”
- Workforce involvement in safety is viewed as the safety practice that benefits the most from implementing lean practices, and is particularly impacted by the 5 S’s, standardized work, etc.

Lean is an approach to eliminating operational inefficiencies through a focus on optimizing business processes. Common goals of lean practices in businesses are to improve productivity, time on task, the flow of work, and the value-added to the final product with each work task. Lean practices have indicated that improving businesses through applying lean principles naturally leads to enhanced employee safety. Concerning safety practices, employees' involvement in safety is viewed as the safety practice that benefits the most from the implementation of lean practices. It is particularly impacted by the 5 S’s, standardized work, etc. (Gambetese & Pestana, 2014).

Arguably, oil and gas employees are exposed to a more hazardous work environment than most other industries. Iqbal et al. (2021) argue that it is imperative to tackle the problems faced during the operation of a drilling rig to prevent wastage of time and money, as well as huge accidents like kicks followed by blowouts may take place. There is a high risk to personnel working in oil and gas fields and the environment and assets in Oil & Gas Operations.

The application of Information Technology (IT) has transformed industries, and the oil and gas sector is no exception. Nowadays, the major innovations in the oil and gas industry are the field of IT, and it promises to improve not just the operational and financial performance but also Health and Safety issues which is a major concern in the sector. This study uses the emerging technology of Artificial intelligence (AI) machine learning algorithms in oil and gas upstream sector injury rate prediction. It is assessed that employees in the oil and gas industry are over seven times more likely to be injured than in other sectors. Adding these issues to the environmental concerns caused by the industry has made it necessary to look for sustainable solutions (Somone, 2020).

2.8 Employee body parts that frequently injured at the workplace

The oil and Gas Industry (OGI) faces a number of evolving and various types of risks and hazards that give rise to severe incidents. The study by El Bouti & Allouch (2017) revealed that three-quarters of occupational work-related injuries (OWRIs) did not occur in High-Risk Activity (HRA), and half of the incidents took place with no tooling involved. Prominently, the main recurrent and frequent event was struck against or by (SAoB) that resulted dominantly in slight injuries that required only first aid care, and the most affected body part is the finger by “Cut (Laceration)/ Pinch.”

Statistics show that every 15 seconds, one employee dies from an OWRI, and 153 employees have a work accident. In addition, on a global scale, 6,300 people passed away daily due to OWRI or work-related ill-health. These work accidents negatively affect the company's performance, bottom line, and economic growth Hämäläinen et al., 2005. These above-mentioned figures related to the occupational accidents and diseases reported and recorded globally do not reflect the real safety record situation of most companies since there are underreporting cases, especially in developing countries. So, the real figures are likely to be far higher than the current recorded ones (Nenonen et al., 2010). A few catastrophic cases of these incidents receive public attention (Hämäläinen et al., 2005; ILO, 2003).

The Swiss Cheese accident causation model, Fig 2.5, is the most practiced in the oil and gas industry safety system to analyze hazards and risks and apply the appropriate mitigating and preventing measures.

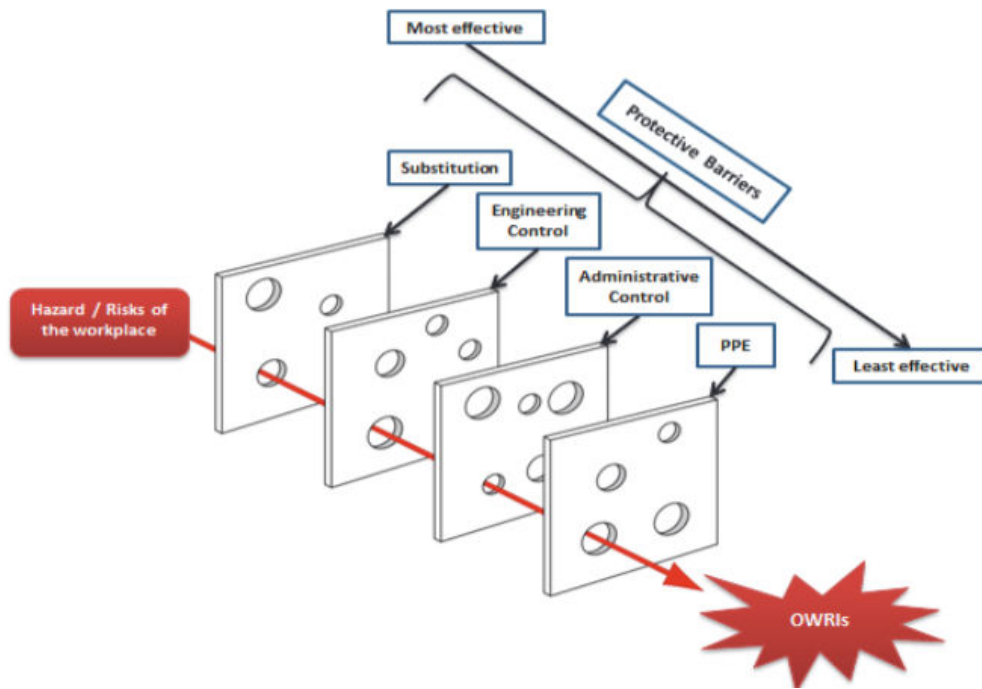


Figure2. 5 Swiss cheese model of accidents causations, Stein & Heiss, 2015

Surprisingly the industry is encountering personal injuries related to not high-risk activities, Fig. 2.6. This could be complacency from senior employees when performing routine jobs and lack of risk awareness and hazard identification skills and training from the side of new employees.

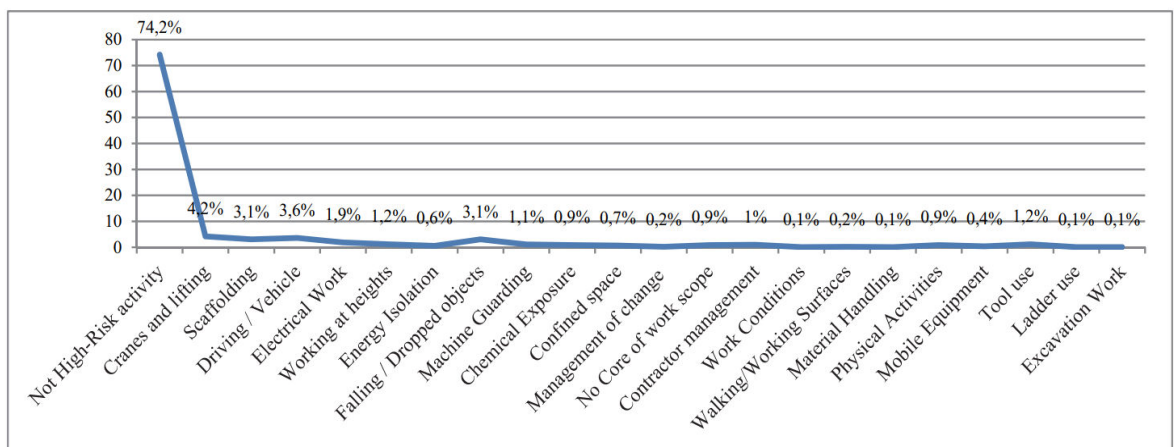


Figure2. 6 The rate of High-Risk Activities implicated in the OWRIs From 2014 to 2016, El Bouti & Allouch, (2017)

As is the case for the not-high-risk activities, it is also evident that no tooling is involved in most of the incidents that happen in the industry, Fig. 2.7. These could be expressed in terms of slip, trip, and fall from the same level, (Maynard et al., 2012).

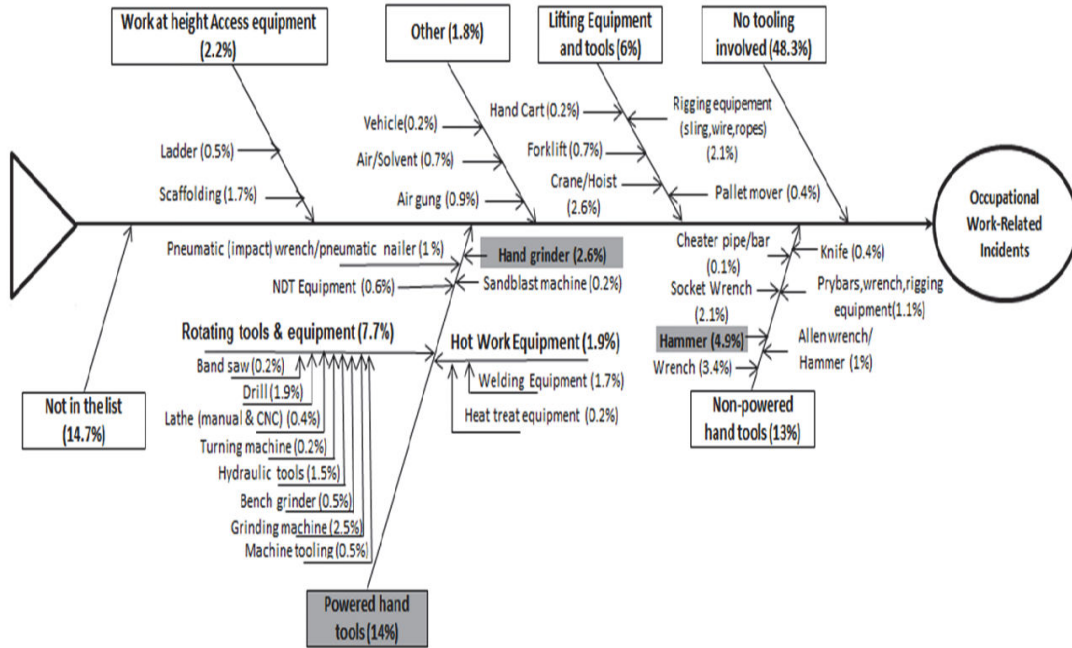


Figure 2. 7 Fishbone diagram of the direct incident cause (Tools used in the workplace), El Bouti & Allouch, (2017)

The upper extremities, fingers, and hand body parts are the most injured parts in oil and gas activities, Fig. 2.8. This aligns with the primary data collected from oil field employees from Supplier Y Company.

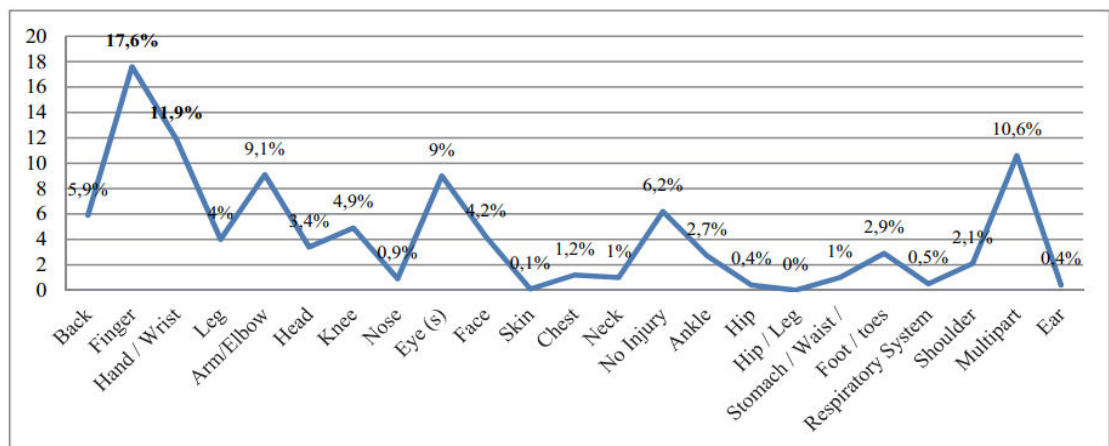


Figure 2. 8 The rate of Injured Body Parts in the Oil and Gas Industry From 2014 to 2016, El Bouti & Allouch, (2017)

As the data from oil and gas activities indicates, El Bouti & Allouch (2017), the upper extremities body parts are the most injured. This is in line with the findings of the primary data

of this dissertation. This dissertation's author conceptualizes a conceptual hand model based on these findings. Please refer to Fig. 4.9 In chapter four of this study.

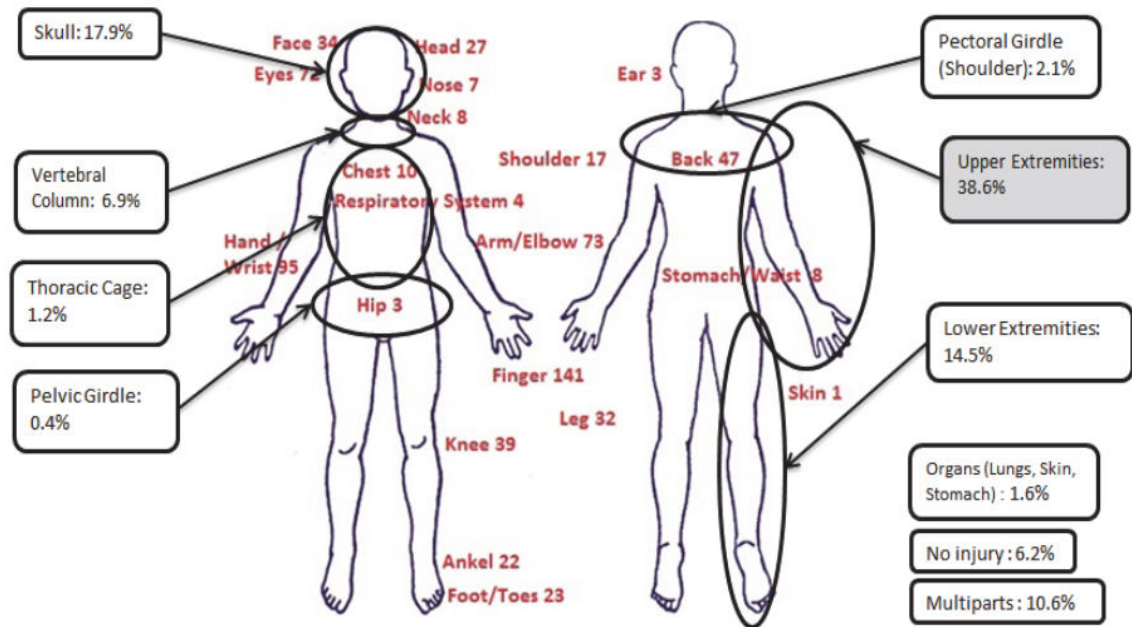


Figure 2.9 The number and rate of Injured Body Parts, El Bouti & Allouch, (2017)

2.9 Employee Engagement & Involvement

Employee engagement is a powerful concept that can improve many business measures, including safety performance. The level of employee engagement directly results from employees' involvement in their work processes and activities. To engage employees in the safety program, management must involve employees when making decisions that could affect their safety. Ideas and feedback regarding their safety must be valued and acted on as appropriate, including follow-up with the employee. Safety communications must be clear and concise and include the reasons for changes. Employees must be given positive feedback when they work safely and always treated with respect. Regardless of the method used, involving and engaging employees in the safety processes will likely result in higher safety performance and an improved corporate culture, which will benefit both the employees and the organization.

Employees to feel that they are engaged in the safety process, the organization must generate several factors:

- employee involvement;

- consideration of employee ideas
- communication;
- positive feedback;
- Respect (Raines, 2011).

Employee involvement in safety changes should be initiated as early as the project. Considering Employee Ideas, employees must feel that their ideas and opinions are valued and will be taken seriously. They should be encouraged to generate views and express opinions regarding workplace safety. When they do so, they must feel that the organization values this input and will evaluate and act on it appropriately to promote the workplace safety system.

2.10 Respect for Employees

Employees must be treated with respect. Safety-related interactions must preserve personal respect, even in disciplinary situations. Leadership support is critical to fostering an environment that supports these factors. This extends to safety personnel. Employee perceptions about organizational commitment to safety are often based on their interactions with safety personnel. Management (including safety personnel) who effectively involve and engage employees when reviewing potential workplace modifications can make a significant difference in the success of such projects (Bonkemeyer & McMichael, 2010; Groover & Spigener, 2008).

Employees may conform to safety rules, but they may assert that safety slackens them down and makes their jobs more challenging. In organizations with healthy corporate cultures, employees know management is genuinely exciting and cares about the workforce. In such a setting, employees will respond with innovative thinking, suggestions, and decision-making that can benefit the organization Erickson, (2000). Mutual respect will likely occur when management, including safety personnel, can engage employees.

Creating a culture of engaged employees and working toward world-class safety can only be achieved when the business has a high degree of trust. Such trust is established one employee at a time Hafey, (2010). Employees want to assert that their employer cares about their safety and well-being, and they also want to feel that their opinions

matter and that their voices are heard. Management should not overlook the wealth of knowledge that employees can contribute. However, gathering this information from employees may be difficult if they do not feel that their ideas will be valued and thoroughly investigated (Raines, 2011).

Safety is not something management does for employees. Management commitment to safety is necessary, but true safety excellence requires employee engagement throughout the organization, especially the frontline employees. Such engagement in safety benefits the employees as well as the organization. Every employee has something meaningful to contribute; people will contribute if the climate is right.

Organizational leaders' day-to-day activities and behaviors form the foundation of an organization's safety culture. Managers at all levels of the organization must exemplify a shared vision of safety excellence and demonstrate the leadership styles and practices needed to drive the desired culture change, including fostering a sense of employee ownership of safety.

To increase the visibility of management support among frontline employees, organizations should continue to emphasize their traditional initiatives, taking special care to ensure the employees communicate and understand the efforts. Employees who assert their work is genuinely appreciated and trusted want to improve and do their best. They become self-motivated (French, & Geller, 2008; Tharaldsen et al., 2010; Krause, 1999).

Injury experience (i.e., whether or not employees have experienced accidents themselves) affects risk perception, their subjective assessment of satisfaction/dissatisfaction with safety and contingency measures, and job stress in the workplace, Rundmo, T. (1995); Han Y et al., (2019). From the secondary and primary data collected, it is evident that most incidents and accidents happening in the oil and gas industry are minor injuries that could be expressed frequently to upper extremities, pinch, laceration, muscle strain, crashes, slips, trips, falls, etc.

Advancing employee health, safety, and wellness through inclusive empowerment programs can help mitigate workplace hazards and enhance the safety climate to influence employees' productivity positively. Baumann et al., (2015). The importance of management commitment in organizations with well-developed safety cultures could

also promote a safe working environment and productive workforce (Cheyne et al., 1998; Mearns et al., 2003; Krause, 2007; Oliver et al., 2002).

'Unsafe' behavior is the 'best' predictor of accidents/near misses as measured by self-report data. That unsafe behavior is, in turn, driven by perceptions of pressure for productivity, Mearns et al., (2001). Unsafe acts mainly cause workplace incidents and accidents, yet most researches focus on unsafe conditions and mitigating and controlling mechanisms.

As the safety climate improves, managers and employees are likely to agree more about the causes of safe/unsafe behaviors and workplace accidents, ultimately increasing their ability to work in agreement to prevent accidents and respond correctly when they occur. Industrial workplace safety requires multilevel support and cooperation. Top-level managers must establish a positive safety climate, supervisors must demonstrate caring attitudes and good examples, and everyone must remove safety hazards and engage in post-incident assessments (Hofmann & Stetzer, 1998; Mearns et al., 2001).

In the aftermath of an industrial accident or “near miss,” employees naturally blame the system (including management) and managers for blaming employees. Managers must be aware of these biases when diagnosing and responding to accidents, Prussia et al., (2003); Mearns et al., (2001). In people-based safety system culture, the primary purpose of safety investigation should not be based on a blame mentality but rather on finding the root causes of incidents and accidents to learn from them to build a continuous improvement safety culture in the organization.

Low productivity and occupational health and safety are the two biggest challenges in executing oil and gas projects. Oil and gas projects have one of the most severe work-related accidents in many countries, leading to declining project performance. Lean management could be an alternative approach to planning, managing, and coordinating oil and gas projects. Accordingly, this new management concept will aid in decreasing the rate of accidents and improving productivity (Dehdasht G. et al., 2018; Marques et al., 2021).

Implementing some Lean tools, such as 5S and Visual Management, to reduce waste by improving the production process has a dual positive impact on workplace safety. The authors argue that the implementation of 5S's allowed the improvement of the visual management and the organization through a reorganization of the layout, as well

as normalization of the production process, which has a direct effect on promoting workplace safety system by creating an organized and tidy work setup, (Sá, J. C, et al., 2021).

2.11 Safety and Competitiveness

Different researchers define competitiveness differently. The World Economic Forum, which has been evaluating competitiveness among countries since 1979, defines competitiveness as “the set of institutions, policies, and factors that determine the level of productivity of a country.”

Competitiveness is often interchangeably used with productivity. Productivity refers to the internal capability of an organization, Moon & Peery, (1995); Wahab et al., (2013), while competitiveness refers to the relative position of an organization against its competitors. Competitiveness may also have a distinctly different meaning at different levels of analysis — product, firm, industry, and nation, Moon & Peery, (1995). Porter (1990) argues that the basic unit of analysis for describing competition is the “industry.”

Regarding competitiveness, the groundbreaking research done by Porter (1990) was one of the most popular countries has used firms. Michael Porter introduced the conceptual framework of competitiveness and clusters in his work ‘Competitive Advantage of Nations. Porter (1990) discusses how nations, regions, and firms become competitive in their industries. Some definitions of competitiveness:

- ✓ The primary definition of competitiveness has been “the set of institutions and economic policies supportive of high rates of economic growth in the medium term.”, (Michael Porter et al., 2000)
- ✓ Competitiveness - The progressing globalization of the economy, the mobility of capital, and the ever-shorter periods in which innovations and products are developed oblige all nations and social groups to face new challenges. Today, the prerequisite to economic development and improved competitiveness is a knowledge-based restructuring of the economy (Zofia, 2003)
- ✓ Competitiveness is a multidimensional concept. Three different but interrelated levels can be looked at: Country, Industry, and Firm-level. The economic strength of a country, industry, or firm concerning its competitors in the global

market economy in which goods, services, people, skills, and ideas move freely across geographical borders (Murths, 1998).

- ✓ Firm-level competitiveness is of the most significant interest among practitioners and has attracted the maximum attention of researchers among the three levels of competitiveness (Murths, 1998).
- ✓ The term competitiveness stems from the analysis of firms and is usually thought to be well-defined at the firm level (Aiginger, K 2006)
- ✓ Continuous success, competitiveness, and steady growth require organizations to develop and retain a core of culture, relationships, and critical knowledge and skills (Guillermo Arango et al., 2006).

Nowadays, the competitiveness between organizations is a growing reality. The Lean philosophy has proven to help companies improve their productivity and reduce waste. (Gonçalves, I. et al., 2019).

In today's ultra-competitive business environment, lean manufacturing concepts offer an opportunity to gain a competitive edge in production, safety, services, and other applications. In a lean implementation, a lean team is set about changing its work area to eliminate the sources of waste, create a safer work environment and improve productivity (Bajjou et al., 2017).

Lean manufacturing includes a variety of initiatives, technologies, and methods used to improve productivity (better and faster throughput) by reducing waste, costs, and the complexity of manufacturing processes. Safety is critical in lean manufacturing to yield better, faster, less wasteful, and safer operations (Main, B et al., 2008; Luis, J, 2003).

Nowadays, nearly every organization strives to 'do more with less,' especially given the challenging economy of recent years and the uncertain economic climate for future years. Business executives and operations managers constantly seek competitive advantages to reduce operating costs while improving efficiency without damaging customer satisfaction and quality and compromising workplace safety. One of the most common ways in which organizations are trying to achieve "operational excellence" has been through the use of Lean (methodology and management system), which is focused

on reducing waste and costs while simultaneously improving speed, quality, and customer satisfaction and safety, (Kelby, J. 2014, Sacks, R., et al., 2005).

Lean philosophy has proven to help businesses improve productivity, create a safer work environment, and reduce losses. Lean can give organizations a cutting edge in this age of global competition. As lean and safety have the common goal of reducing waste, there are natural opportunities where they integrate into each other (Pai, P. M. 2010).

Lean management is a performance-based strategy to reduce costs, achieve higher quality levels and increase the competitive advantage of companies. Synergy may be found between the accident pre-cursors analysis, required by the safety management systems, and the knowledge-sharing principle, typical of lean approaches (Andriulo, Set al, 2015; Feutz, P. 2008).

Lean is a collection of ideas, tools, techniques, and initiatives that companies can apply to increase productivity, safety, and throughput. The central premise of lean is to identify wastes (non-value-adding activities) in a process and eliminate or reduce them. To do this, lean suggests the use of tools such as value stream mapping (VSM), kanban, kaizen, pull systems, 5S, one-piece flow, poka-yoke, jidoka, and others. Today's companies are under immense pressure to perform at the lowest cost, highest quality, and focus on safety. lean has emerged as a popular management philosophy for companies to attain that competitive edge.

Accidents bring indirect costs of compensation claims and a forced machine or process shutdown. These are against the fundamental principle of lean to minimize waste. Hence, lean and safety should not be viewed as having conflicting goals but should be addressed simultaneously (Pai, P. 2010; Ward & De Brito, 2007).

Since all safety incidents imply a waste of time and resources, lean and safety have a common ground in minimizing waste. Lean and safety are strongly related to workplace productivity and safety (Prakash, R. 2011).

Safety and lean aim at similar goals in making the business process faster, better and safer, Main et al. (2008). The principles of lean and safety are aligned, and the oil and gas industry could benefit from their integration. Lean methods add value and eliminate waste, and in safety, context helps in risk mitigation, employees' ideas input, involvement, and engagement in solving safety-related problems. Thus, it is evident

that lean and safety synergy can be harnessed to create a safe, productive workplace (Fernández-Solís et al., 2018).

Safety, health, and environmental protection are essential to sustainable growth, Taubitz, (2010). Scholars such as Hafey (2017a) and Taubitz (2010) reveal that there may be an integrated vision of lean production techniques and safety management systems; subsequently, both concepts share points in common.

Hafey (2017a) introduces an integrated vision of lean production techniques and safety management systems. Again, in another research, Hafey (2017b) highlights that a safety culture must not only comply with the regulations but must also go beyond applying the approaches of continuous improvement and employees involvement, typical of the lean paradigm, Andriulo et al. (2015) & Gnoni et al. (2013) propose the integration of lean management principles with occupational safety.

Brown & O'Rourke, (2007) discuss how the lean manufacturing approach impacts the risk assessment related to new types of risk generated by the logic of flexibility and configuration of the production line. They also emphasize that focusing on employees' participation in identifying and solving problems is critical for reducing negative impacts. Developing informed, empowered, and active workers with the knowledge, skills, and opportunity to act in the workplace to eliminate or reduce hazards are vital for occupational safety in a lean production context (Dieste M et al., 2020).

Longoni et al. (2013) compare ten case studies from lean thinking and safety joint perspective. Results demonstrate that adopting lean practices, or an overall lean philosophy implementation, positively impacts operational, health, and safety performance.

Taubitz (2010) asserts that if incidents and accidents are considered waste within corporate sustainability, reducing waste should also improve the safety conditions in any continuous improvement activity or project.

Lean and Safety principles are intrinsically similar and are integrated into the day-to-day operations of a Lean management business process to create a world-class product that exceeds customers' expectations, where businesses produce an injury-free, hazard-free work environment (Williams, J. 2005).

Businesses are looking for innovative tools and techniques to manage projects optimally and achieve higher safety performance. In order to eliminate or possibly prevent errors in business processes, it is essential to prevent errors and redesign the processes. Several tools and techniques prevent errors and make workplaces safer (Demirkesen & Zhang, 2021).

When errors in processes happen and perhaps lead to safety incidents and accidents, accident investigations could use ‘Five Why’ techniques. The purpose of using the Five Whys in organization was not to identify exact root causes but rather to challenge investigators to look beyond usual causes, i.e., to deeper underlying and contributing factors. Accident investigation should try to illuminate unsafe acts in the context of preconditions for unsafe acts, unsafe supervision, and organizational influences (Rasmussen, 1990; Leino & Helfenstein, 2012).

2.12 Safety Leading and lagging indicators

The oil and gas industry continues to experience high accidents and fatalities, rendering safety a major concern for oil and gas companies. Safety performance must be monitored and assessed before incident occurrence to develop more effective, proactive strategies to reduce future accidents. Safety leading indicators can proactively assess safety performance, provide insights into the effectiveness of an organization’s safety practices, and offer guidance on how to improve (Mohamed, E et al., 2019).

The observation of safety leading indicators provided a measure of safety risk at the workplace and a measure and mechanism for continuous learning. The Lean principles of planning, measurement, adjustment, and improvement (“Plan, Do Check, Act”) could be applied to the workplace setting, considering the current state at the Gemba. Communication of goals, measurement of performance in relation to those goals, and a culture of accountability for measured performance can lead to the safer and more efficient execution of business processes in a safe manner (Laurlund et al., (2012).

A leading indicator measures attitudes, behaviors, practices, or conditions that affect workplace safety performance, Hinze et al. (2012); Guo &Yiu (2016). The careful selection, measurement of, and reaction to leading indicators of safety performance in

the workplace all have helped to improve work-site safety and organization (Ng et al., 2012; Hinze et al., 2012).

Hinze et al. (2012) classify leading indicators as passive or active. Passive indicators are a set of strategies and actions that are set up prior to the commencement of projects and cannot be adjusted once the project has started, Hinze et al., (2012); Akroush & El-adaway, (2017). While, active indicators can be measured and adjusted dynamically during ongoing project phases, allowing for the real-time implementation of risk mitigation practices, Akroush & El-adaway, (2017), Hinze et al., (2012). The safety management system is recognized by safety leading and lagging indicators and their correlation with injury rates.

Table 2.2 Safety leading and lagging indicators: Source, Neamat, (2019).

Year	Leading Indicators														Lagging Indicators				
	Alcohol / Drug Testing	Attitudes and Safety Climate	Fall Protection	Housekeeping	Ladders and Stairs	Near Miss	Pre-Task Safety Plans	Personal Protection Equipment	Railings and Covers	Safety Corrections	Safety Positive Reinforcement	Site Inspections / Audits	Subcontractor Safety	Training / Job Safety Talks	Worker Safety Behavior	First Aid Injuries	Lost Time Injuries	Members of the Public Injured	Reported Incidents
2010			✓	✓	✓			✓	✓	✓									
2011		✓								✓			✓	✓	✓	✓	✓		
2012			✓	✓	✓			✓	✓	✓									
2012		✓				✓	✓			✓	✓	✓			✓	✓			
2013		✓				✓					✓	✓	✓						
2013						✓	✓							✓	✓	✓			✓
2014	✓	✓	✓	✓				✓		✓								✓	
2015		✓		✓			✓						✓	✓	✓	✓	✓		✓
2015												✓	✓	✓					
2016		✓													✓				
2017	✓						✓			✓				✓			✓		
2017		✓												✓	✓				
2018		✓				✓												✓	✓
2018															✓	✓	✓	✓	✓
2018		✓																	
2019	✓		✓	✓	✓	✓		✓			✓					✓	✓		
2019						✓					✓	✓	✓	✓	✓				
2019		✓					✓					✓	✓	✓					✓

The lean application could improve safety by addressing factors such as poor work methods, the physical and mental inability of employees, poor communication, and poor planning, among other causes of accidents identified by several studies (Bashir, A. M., et al., 2011; Ikuma, L. H et al., 2011).

Compliance with safety regulations is insufficient to eliminate accidents and assure a safe environment, Gambetese & Pestana, (2014). Improving safety in oil and gas remains a priority in almost every country worldwide since the oil and gas industry stands out among all other industries as the main contributor to severe and fatal accidents (Ghosh & Young-Corbett, 2009).

Workplace accidents and injuries are considered a major source of waste in oil and gas businesses, leading to high costs. These accidents introduce variability in the production process, resulting in major workflow disruption, which lean safety aims to stabilize

Gambetese & Pestana, (2014). In addition, lean management processes can effectively reduce injury related to oil and gas accidents and improve employees' performance (Zhu, 2014).

Ikpe et al. (2012) conducted a cost-benefit analysis regarding accident prevention. Their findings show that the benefits of accident prevention outweigh the costs of accidents by a ratio of 3 to 1 (Ikpe et al. 2012).

2.13 Lean Culture and safety

Relihan et al. (2009) defined safety culture as “the product of individual and group values, attitudes, perceptions, competencies, and patterns of behavior that determine the commitment to, and the style and proficiency of, an organization’s health and safety management.” According to Wu et al. (2010), safety culture refers to employees’ vision of safety conditions that affect safety outcomes. Consistent with Wu et al. (2010)’s view, in this study, safety culture refers to the employees’ awareness of workplace safety conditions, which then affects organizational safety success.

The importance of a safety culture to maximize safety is no longer questioned. Lean management is such an integrated approach to improving safety, quality, and efficiency and, therefore, could be expected to improve the safety culture, Simons, P. A., et al., (2015); Pitts, J. (2021); Maestas & Parrish, (2014). It was found that lean management creates opportunities for improving safety culture (Morshidi, Z. (2020).

Lean culture is not ONE thing:

- Lean is a culture of continuous improvement practiced at every level of the organization and by every team.
- Lean is applying the scientific method of experimentation and study of work processes and systems to find improvements.
- Lean is respect for people. It is respect for the voice of the customer, and it is respect for those who do the work, who are “on-the-spot” and are, therefore, the “world’s greatest experts” in their work.
- Lean is the elimination of waste in all its forms. Lean is the ability to distinguish between work that adds value to company customers and

work that does not. By eliminating waste, companies have free resources to devote to value-adding activity that serves customers.

- Lean is a work environment that assures the quality and safety of all work for customers and staff.
- Lean focuses on improving the work process, not blaming people or creating fear.
- Lean is a culture of teamwork, shared responsibility, and ownership that cuts through organization walls or silos.
- Lean is a culture that returns the joy to work.
- Lean is flow. Lean is an interruption-free process that flows from beginning to end without interruption, Miller, L. M. (2015).

It is common to hear the usual argument, what is different about lean that makes it different from other operational excellence methodologies? Various authors have their justification to explain what is special about lean as a management and production tool and methodology; their shared view would be lean is different because of the lean culture embedded in the methodology.

There is a missing link in most lean manufacturing descriptions; lean culture and a lean management system to go with it, David Mann (2003). Organizational culture is the organization's daily working practices, problem-solving habits, knowledge sharing and communication systems, customer handling and working discipline, safe working practices, etc. Lean culture grows from the working practices when the practices become habitual, a way of thinking or mindset (David Mann, 2003).

One of the crucial competitive advantages of an organization is its workforce. A workforce that is aligned to the overall company mission and vision, and workforce that are engaged in doing the day-to-day task and oriented to problem-solving and innovative thinking, and on top of that workforce that is respected in suggesting how to continuously improve the process in value-adding and working it safely, is a happy employee. Lean culture contributes hugely to an engaged and committed workforce (Angelis et al., 2011).

A typical example of observing lean culture in an organization could be evaluating and seeing the following common practices at the ‘Gemba,’ the place where the real value is created, David Mann (2003):

- ✓ What are inventory practices around here?
- ✓ How often does management look at the status of production here?
- ✓ Who has been involved in process improvement activities in this area?
- ✓ How often do employees suggest improvement ideas, and their ideas are implemented.
- ✓ What is the culture of continuous improvement in creating customer value and employees’ value by creating a safe working environment?

Najem & Bennett (2012) argue that factors such as top management commitment and leadership, empowerment and training of human resources, building relationship with suppliers and customers, enhancing departmental relations, and teamwork must be considered to implement a successful lean culture.

2.14 Change Strategies towards a Sustainable Lean Safety

Sustainable development is often framed as a social issue to which corporations should pay attention because it offers opportunities and challenges. Oil and gas multinationals are subject to sustainable development pressures – climate change, biodiversity, the safety of personnel and environment protection, renewable energy development, and social investment, Escobar & Vredenburg, (2011). Access to clean, affordable, and reliable energy has been a cornerstone of the world's increasing prosperity and economic growth since the beginning of the industrial revolution. Our use of energy in the twenty-first century must also be sustainable (Chu & Majumdar, 2012).

Sustainable development is an attempt to combine growing concerns about a range of environmental issues with socio-economic issues. Sustainable development has the potential to address fundamental challenges for humanity, now and into the future, Hopwood et al., (2005). As it is evident, one of the main targets of lean thinking is process waste elimination, which has a direct implication on sustainable development by utilizing resources efficiently and effectively for the good and value of the customer

in particular and society in general with the workforces safety and wellbeing given high priority.

Macroeconomic definitions of sustainability center attention on the need to maintain aggregate stocks of natural and manufactured capital constant over time so that future generations have access to natural resources similar to those of the current generation. To perform realistic assessments of a firm's sustainability, for that reason, one needs to consider its overall economic performance as well as its environmental performance (Reinhardt, 2000; Weiss, 2010).

2.15 Change Strategies towards a Lean HSE

Industrial accidents, explosions, and fires have a depressingly familiar habit of re-occurring, with similar if not identical causes and patterns. There is a continual stream of significant losses commonly ascribed to poor operating and management practices, Duffey (2007). Oil and gas companies face increased health, safety, and environmental pressures from past and recent significant accidents that negatively impact the environment, industry image, and social lease (Bigliani, 2013).

Management commitment to safety is essential to an organization's safety culture, Reason J. (1997). O'Dea & Flin (2001) analyzed management's difficulty in motivating and controlling some crucial safety aspects of workforce behavior, such as getting workers to accept ownership of safety and reporting near misses, unsafe acts, and unsafe conditions.

In most organizations, blame culture is the obstacle to the workforce for not reporting problems and operational safety issues. In the lean community, there is an encouraging trend that lean thinkers assume that it is the broken process to blame for the problems, not people; people are part of the solution, not the problem. In terms of outstanding safety issues, it appears that improvements still need to be made in several areas, such as the standardization of safety culture; the coordination of safety practices and procedures across the offshore oil and gas industry; improved workforce competency, and increased workforce involvement in safety activities and decision making, (O'Dea & Flin, 2001).

Unfortunately, accidents in the oil and gas industry have a long-lasting effect on the environment and assets. Risks related to assets, business interruption, pollution, injuries

to people, and damage to reputation are intrinsic in normal oil and gas activities, Bigliani (2013); Mearns & Yule (2009). Risks and uncertainties penetrate every aspect of the exploration of petroleum resources, and environmental risks are not unique in this sense, Hasle et al., (2009). As oil and gas exploration activities go to the most remote areas, usually sensitive regions in terms of their biodiversity makeup, such as the Arctic Circle and the Barents Sea, extra caution in environmental impact assessment, personnel safety management, risk management, local content, and making an integrated effort by all players and stakeholders required.

Increasingly, companies are considering environmental differentiation as a basis for their competitive advantage, Roy & Vezina (2001); Sharma (2001). The global oil and gas companies are extra conscious about the environmental footprint the oil and gas operations have on the environment where they operate, not to pollute the ecosystem, such as the soil, water, fishing activities, air, etc. Multinational oil and gas companies are taking extra measures to improve their environmental management practice as a competitive measure.

As companies formulate and implement their strategy, they are voluntarily formulating the most stringent internal environmental regulation, taking extra measures to protect the environment around their activities. Promoting safety as a value is a winning strategy that could generate wealth for the company and motivate employees. It could also sustain employees by creating a safe working environment for the employees and help the company keep its goodwill and reputation.

2.16 The Global Oil and Gas Value Chain

The oil and gas industry's increasingly competitive and global nature has driven companies to keep a close eye on cost and performance issues and to seek opportunities to innovate, enhance revenues, and reduce inefficiencies (Tenera & Pinto, 2014).

In an environment of rapid growth, significant technological changes, and increasing acquisitions and divestitures, successful companies understand that monitoring performance through benchmarking is a critical strategic tool, Wipro Ltd; Holweg, (2007). There may be no other industry today that demands a more diverse set of human,

political, mechanical, and technological capabilities and safety innovations than the oil and gas exploration and production industry (IBM Business Consulting Services, 2004; José Moyano et al., 2012).

Oil and gas companies are now more global, and some are becoming more processed-based. Some are following a strategy where the company's portfolios are such diverse that doing business from conventional hydrocarbon exploration and production to a clean energy mix of renewable energy endeavors. Cross-functional stakeholders increasingly demand more difficult results to achieve, given the ongoing economic uncertainty and challenging market conditions impacting the industry (EYGM Limited, 2013; Bortolotti et al., 2014).

Low natural gas prices and oil price uncertainty are forcing upstream companies to focus on improving efficiency and reducing costs. This research focuses on upstream oil and gas offshore the Norwegian North Sea. The capital and operating costs for offshore deep-water wells, unconventional resources such as oil sands, and horizontal drilling techniques cost more than conventional onshore reserves, compounding the industry cost challenges (EYGM Limited, 2013). That is where continuous process improvement needs to be the top priority of all workforces in general and top management in particular (Pampanelli et al., 2013).

Continuous process improvement is a management philosophy that can benefit customers, shareholders, employees, and suppliers. Companies facing capital and operational cost constraints within the oil and gas sector must employ continuous process improvement programs and tools to help drive down costs and improve their bottom line (EYGM Limited, 2013; Bamber et al., 2014).

One of the operational excellence methodologies that the author of this study would assert fit for continuous process improvement and safe working culture in the oil and gas industry could be lean philosophy. It would provide the cultural setup and mindset and the paradigm shift in workforce engagement and problem-solving capability and value innovation from the perspective of the customer value and employees' safety and continuously striving for improvement towards perfection.

The global oil and gas value chain comprises three sectors: upstream, midstream, and downstream (Fig 2.10). The main focus of this dissertation is the upstream sector, and it mainly analyzes the oil and gas upstream exploration in North Europe Norwegian continental shelf.

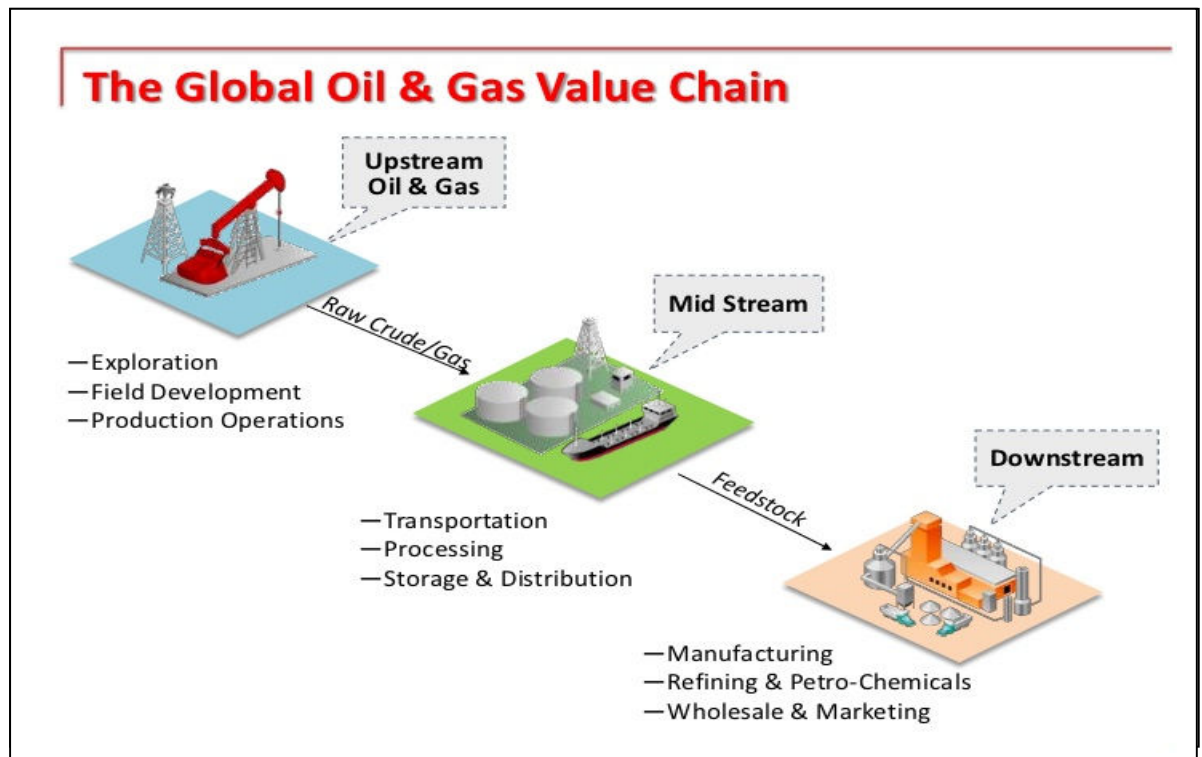


Figure 2.10 the Global oil and gas Industry value chain

Source: (The Global Oil & Gas Industry: Prospects & Challenges in the Next Decade, 2012)

The upstream sector's main activities are searching for and finding oil and gas reserves, developing the facilities, and producing oil and gas in the form of crude oil and natural gas, commonly called Exploration and Production (E&P).

As this study focuses on the upstream sector of the oil and gas industry, the sectors' main activities are as in Fig 2.11 below.

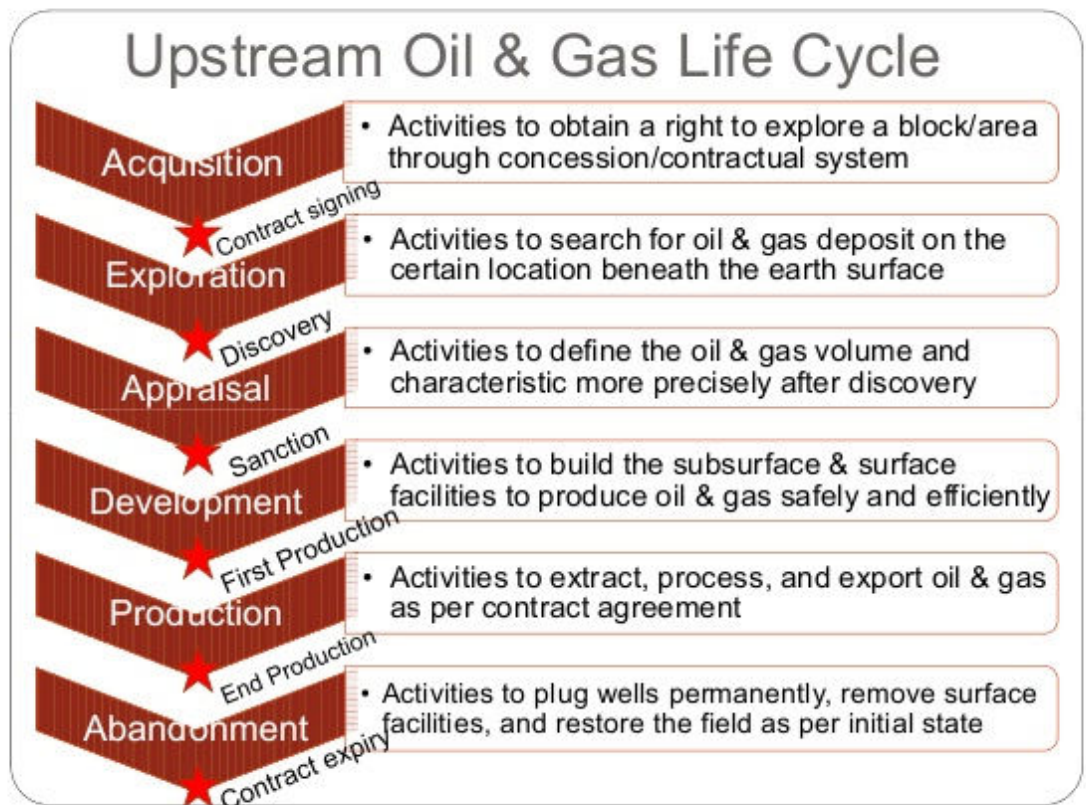


Figure 2. 11 Upstream Oil and Gas sector Life Cycle

Source: (The Global Oil & Gas Industry: Prospects & Challenges in the Next Decade, 2012)

2.17 Oil & Gas Industry Current Trend

The current extended oil price downturn will likely have long-term effects on the industry in several areas, including capital allocation and the availability of a skilled workforce. One can see the less appetite in the industry for long-term and complex major capital projects. This trend of deferred long-term complex capital projects would influence the future supply of oil and gas (oil and gas industry outlook, 2017; López, 2015).

The industry has several challenges with multi-layer situations where some lead to long-term effects, which influence the global energy supply when the demand returns to normal. The industry must implement sustainable strategic measures that could give the industry a competitive advantage to offset price and demand volatility, which are occurring following some forms of cyclic nature. A short-term firefighting kind of quick

fix would not be a solution to the strategic problem the industry has been facing. All rounded root-cause problem analysis strategies to position the industry in a way that enables it to work out the cyclic downturn the industry has been facing for some time now.

Some of the dramatic, vibrant happenings the industry entertaining today are:

- Low oil price, demand volatility
- Minor to major accidents and incidents
- Downsizing, short-term-focused projects
- Merging, divesting
- Cost Cutting, layoff, skill gap, seniors leaving the industry
- High Cost of project development
- Remote Reserves, a rare significant discovery
- Stringent Regulatory Requirement
- Some Projects are shelved, and mega capital projects are deferred.

This dissertation's research questions are designed to capture the multi-layered problems the industry is facing. Thus, the research outcome would address the current issues and questions raised.

The oil and gas industry, by its nature, has a very complex supply chain that leads to the industry being exposed to some common risks, such as the one mentioned below, fig 2.12

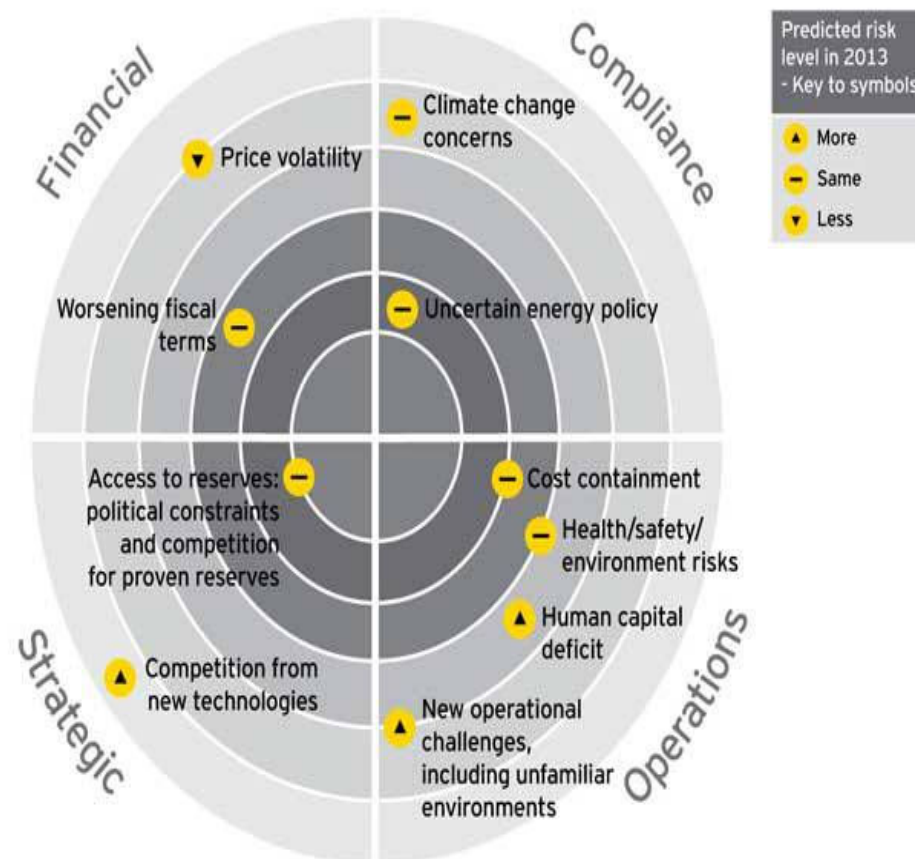


Figure 2.12 Various risks oil and gas industry facing, Source: (IntelligentHQ, 2012)

As shown in Fig 2.12, the risk level from the competition of new technologies is ever increasing. A typical example of this is the substitution of fossil fuel for Battery electric cars, which has gained momentum through government policies in most developed countries by way of initiatives to counterbalance the environmental footprint of fossil fuels.

It is also evident from the Fig 2.12 that the industry's human capital deficit is growing at an alarming rate as the most skilled senior workforces are leaving the industry through retirement.

The aftermath of a crude oil price drop, which started in July 2014, has had a long-term negative impact on the industry as a whole. The industry is faced with internal and external factors that decide the future performance of the industry.

Fig 2.13 below projects the impact of external forces on the oil and gas industry operation. As the projection depicts, the impact of technology, environmental concern

towards the operation of the industry, proactive involvement of world leaders, and government influence show an increasing trend. It could be a ringing bell for the oil and gas industry that emerging alternative energy availability would increase from 27% to 47%. Furthermore, skilled workforce availability would show a critical decline.

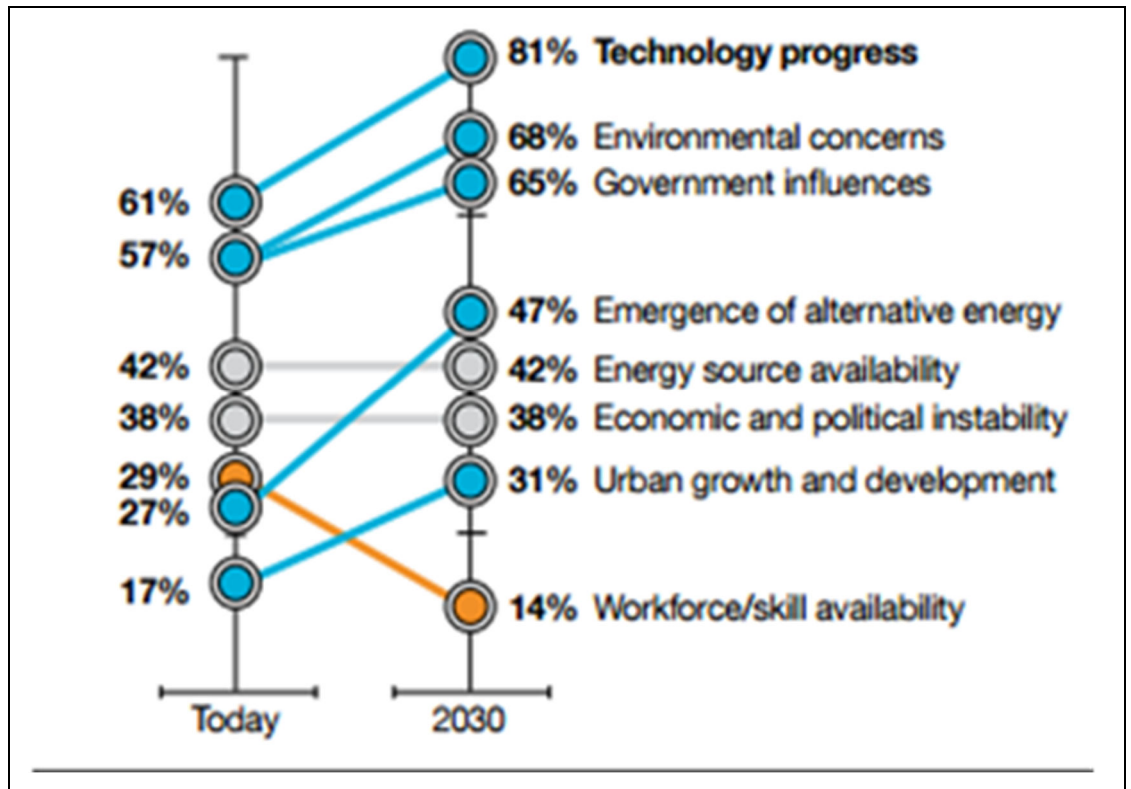


Figure 2. 13 Influences of external forces in the coming two decades, on oil and gas industry (IBM Institute for Business Value, 2010)

2.18 Operational Excellence Methodologies

Operational Excellence has its roots in the successes that Toyota realized with its famous Toyota Production System, bearingpoint.com; Spagnol et al. (2013). Operational excellence is considered a competitive weapon for firms. Operational Excellence is a method and philosophy aimed at accelerating and improving processes, resulting in lower costs and higher customer satisfaction, in creating a safe working environment (bearingpoint.com; Bamber et al., 2014).

Focusing on continuous improvements in the firm's business operations can gradually achieve excellence, longing for perfection to keep the momentum. Operational Excellence (OE) then becomes a robust competitive advantage. OE also involves the Continuous Improvement (CI) of the efficiency and effectiveness of one's business processes (MCE, 2013; Holtskog, 2013).

Excellence is defined as “a combination of operational excellence (efficiency) and service excellence (effectiveness).” The right business excellence models that fit the company’s business context benefit sustaining excellence and doing a noble business. More precisely, business excellence models appear to overemphasize value creation while underemphasizing the means of capturing this value. Moreover, they often lack a strategic component, including concepts such as strategic choice, alignment, and sustained competitive advantage (Matthias et al., 2018).

Shingo (1987) stated, “Think in terms of categorical principles.” The Shingo house is a categorization of the guiding principles of operational excellence. Associated with each category are also listed many important supporting concepts? The principles are categorized into four dimensions: cultural enablers, continuous process improvement, enterprise alignment, and results (Shingo Institute).

One can choose several business tools and techniques for performance improvement, make one’s business efficient, effective, and competitive, win market share from competitors and grow business, and make the working environment safe and processes innovative. The focus of this study is not to choose a bunch of tools and techniques for business performance. The objective is to employ a continuous business improvement philosophy that best fits the context of the oil and gas industry business processes and safety systems. To this end, in the endeavor to do ‘more with less ‘resources, to do businesses safer and with high value for customers, and a competitive strategy that makes the oil and gas industry the future reliable source of energy with less impact on the environment. In the innovation process, there is no one-size-fits-all. So, companies should look at the right tools rather than the popular tools (Gronlund, 2013; Salehia & Yaghtin, 2015).

Projects managed using lean management are safer because they follow the lean principle of Respect for employees, which creates a sense of psychological safety within the project team. Prerequisites for individual and team learning behaviors such as experimenting, requesting feedback, talking about errors, and asking questions contributes to a safety culture (Howell et al., 2017).

Lean Management is a friendly methodology to continuously and systematically achieve process improvement, helping the organization look for operational excellence that leads to overall excellence (Palmira, 2012).

Some of the justifications behind using operational excellence methodology in the oil and gas industry more than any time ever would be:

- Today, more than ever, companies looking to create new growth have methodologies and tools at their hand to help reduce risk and increase the odds of success.
- The need for operational excellence (OE) has never been greater for oil and gas executives. Exploration, development, and production costs are rising, and refining margins are under pressure.
- The oil and gas industry is under tremendous pressure to reduce risk, even as it takes on new challenges, such as drilling in ultra-Deepwater.
- Intensive onshore operations in populated areas.
- Rising expectations of regulators, shareholders, and the general public.
- Minor to major accidents is resurfacing from time to time.
- Regulations are becoming increasingly complex and regulators more proactive, requiring greater attention to ensure compliance.
- Operational excellence creates value through systematic and repeatable actions that are clear and addressable for everyone in the company,
- Operational excellence allows oil and gas leaders to confidently say and prove that they are running their assets safely, reliably, sustainably, and cost-effectively (Bain & Company, 2013).

The operational excellence methodology deemed fit for the multi-faced problem the oil and gas industry currently faces would be the continuous improvement methodology of lean thinking. Lean thinking has been proved in the Manufacturing and Healthcare industry and has generated a competitive advantage in creating customer value, employee safety, and eliminating process wastes.

2.19 Lean for Upstream Oil and Gas context

Continuous improvement requires a sustained effort, Holtskog (2013), which has been a significant challenge to the petroleum industry. People in the petroleum industry are

often unconvinced of the benefits of a long-term commitment to quality and continuous improvement programs because they have seen several improvement systems come and go without a clear, lasting impact.

Lean is another quality-improvement methodology focused on optimizing the customer-value chain and creating a safer working environment for employees. Lean was developed in the automotive sector but has transitioned into various industries (Buell & Turnipseed, 2004; Demeter & Matyusz, 2011).

Despite its success in practice, the lean philosophy and methods have not been thoroughly evaluated and incorporated into the academic literature, Ballard & Tommelein (2011). One of the pertinent issues is the adequacy of lean methods for managing complex projects like the one in the petroleum industry. As project complexity increases, emergent phenomena increase. Consequently, leadership must become more adaptive and less prescriptive to manage projects (Ballard & Tommelein, 2011) successfully.

Applying lean to the oil and gas industry, as with any industry, requires a fundamental understanding of the philosophy rather than attempting to copy how Toyota – or anyone else – does it. The current condition, future desired state, challenges, problems, the value from a customer perspective, and employees' involvement and engagement are the elements to be contextualized in applying lean thinking for Oil and Gas safety.

When workforces in an organization begin to understand lean indeed, particularly the Plan-Do-Study-Act (PDSA) cycle, Deming (1986), they begin to see it as a system of improvement, and the approach becomes much more focused on identifying and sticking with what is vital to the organization. There is a common sentiment in the lean community that employees are not only doing the job, but they are also the ones with hands-on experience and knowhow to improve, practically solve day-to-day problems, and continuously improve the process. Regarding safety processes, it is in employees' best interest to suggest and improve continuous safety systems. There is a common belief in lean thinking that people are not the problems. They are part of the solution.

Fig 2.14 below illustrates Deming's (1986) PDCA cycle of continuous improvement and problem-solving methodology. Continuous improvement is one of the pillars of lean philosophy.

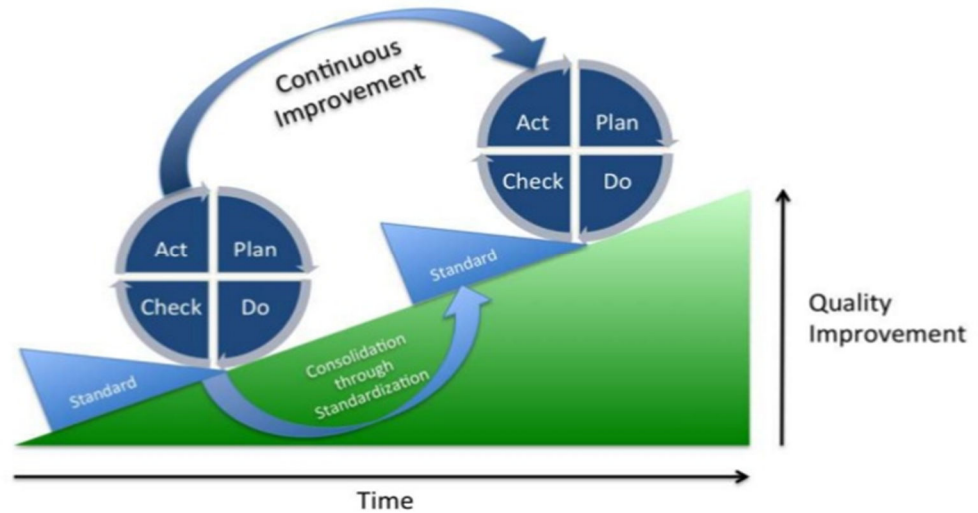


Figure2. 14 Deming Cycle, Source: Deming Institute

The following eight steps problem-solving methodology clearly shows that in the PDCA cycle, the planning phase takes most of the analysis process.

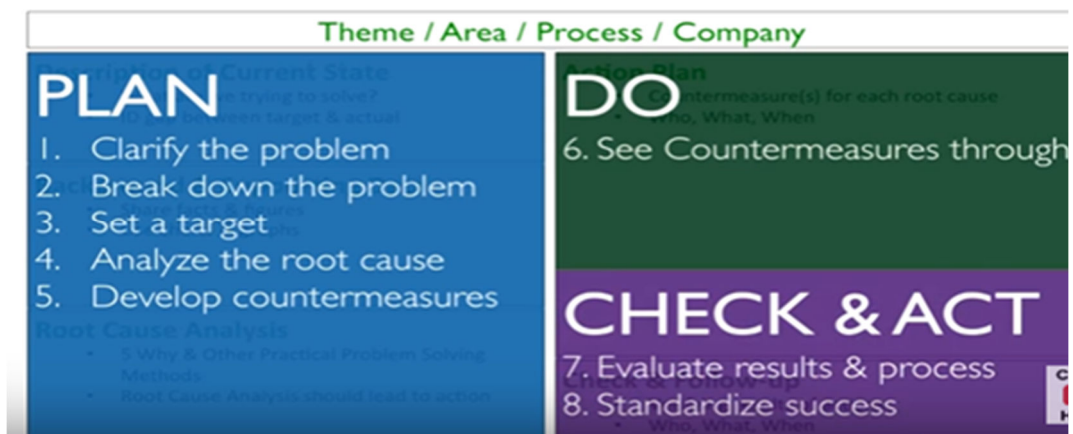


Figure2. 15 Problem solving, (Gemba academy, 2009)

The PDSA cycle drives learning through conscious testing, proving or disproving, and adjusting hypotheses. An oil and gas exploration campaign, for example, is driven by a hypothesis that a certain amount of recoverable oil and gas resides in a specific area. Although a failed exploration can cost a company a lot, it is even more costly when the team does not use the information to learn and improve the process for future projects (Gemba academy, 2009).

Within oil and gas exploration, the PLAN phase in the PDSA cycle could be a hypothesis about how much recoverable oil and gas exist in place. Geophysical seismic analysis is done to capture the potential prospect of commercial oil and gas reserves.

The DO phase could be the drilling of exploration wells; this is the capital-intensive and technology-based process employed. It is also the most hazardous operation.

The STUDY phase could be the review of samples and data from the drilled exploration wells to determine whether to proceed with the project; data collected from the drilling process is primary data that confirms the prospects of commercial viability and reserve volume.

ACT could be the action taken because of the study phase, including adjusting the exploration process to improve future performance (Gregg Stocker, 2014). The ACT phase is the phase where learnings acquired from the previous phases are applied in the continuous coming phases.

Deming (1994) proposes that processes should be analyzed and measured to identify gaps and variations concerning what customers want. The continuous feedback method Plan-Do-Check-Action (PDCA) is a closed-loop system that enables continuous improvement and problem-solving endeavors (Filardi et al., 2015).

As evident in Fig 2.15, the planning phase of the problem-solving process takes up much of the endeavor of the PDCA process. One of the common mistakes people make in the PDCA process could be jumping to the DO phase without a thorough planning phase.

2.20 Supply Chain Relationship and Quality Concerns in the Upstream Oil and Gas Sector

Supply chain (SC) is a dynamic process that entails a continuous flow of information, materials, and funds across multiple functional areas, within and between chain members, to meet customers' requirements and maximize their profit, Shatina Saad et al. (2014). The Oil and Gas industry offers a classic model for implementing supply-chain management techniques, Chima Christopher (2007). The upstream offshore oil and gas activity has the most complex supply chain. The remoteness, most hazardous conditions, and challenging weather conditions of offshore upstream oil and gas

activities are some factors that result in extra costs and project delays in the offshore supply chain.

The new trend of organizational competition has shifted from firm to firm competition to competition along the supply chain. It is imperative to consider every link in the supply chain and support with clear supply chain visibility and a communication plan to strengthen the weak link in the supply chain. Inefficiency, incidents, accidents, or any issue and delay and flaw happening in one part of the supply chain affects directly or indirectly the whole supply chain.

Organizations need to work out how best to leverage competencies, resources, and skills across their supply chains (SCs) to compete effectively and manage costs and customer value (Mohammad dust et al., (2015). The new paradigm of cost and value management would be not by cost-value trade-off but by using lean management to create value from a customer perspective and eliminate process waste that could add cost to the process. Moreover, creating a safe work environment for the employees and workplace empowers workforces in the involvement of processes continuous improvement.

Farzad & Kuan (2011); Alsayigh (2015) assert that the concept of lean and supply chain management has recently emerged from lean production. Globally, supply chain professionals have been tasked with reducing waste, increasing turnover, and building greater flexibility in their supply chains. Some of these areas overlap with lean thinking. There are six major attributes of the lean supply chain, Alsayigh, (2015) :

- ✓ Demand management;
- ✓ Cost and waste reduction,
- ✓ Process Standardization;
- ✓ Industry Standardization;
- ✓ Cultural change;
- ✓ Cross-enterprise collaboration.

Mollenkopf et al. (2010) argue that the lean supply chain strategy focuses on reducing waste and eliminating non-value adding activities related to equipment, tools, time, labor, inventory, and space across the supply chain. The lean supply chain strategy

enables organizations to ensure the best quality of services and products and reduce costs. Due to the widespread acceptance of lean supply chain practices and growing pressure for environmental management, firms have begun incorporating environmentally friendly practices into their waste reduction schemes.

Supply chain management in the petroleum industry contains various challenges, specifically in logistics, that is not present in most other industries (Raed Hussain et al., (2010). In today's market environment of low crude oil prices, the industry needs to optimize and implement operational excellence methodologies that could offset the challenging aspects of the upstream offshore oil and gas supply chain. Despite the significant challenges in the petroleum industry's supply chain, opportunities for improvements and process waste elimination exist along the supply chain (Raed Hussain et al., 2010).

Fig 2.16 depicts a typical oil and gas supply chain, linking the upstream and downstream sectors.

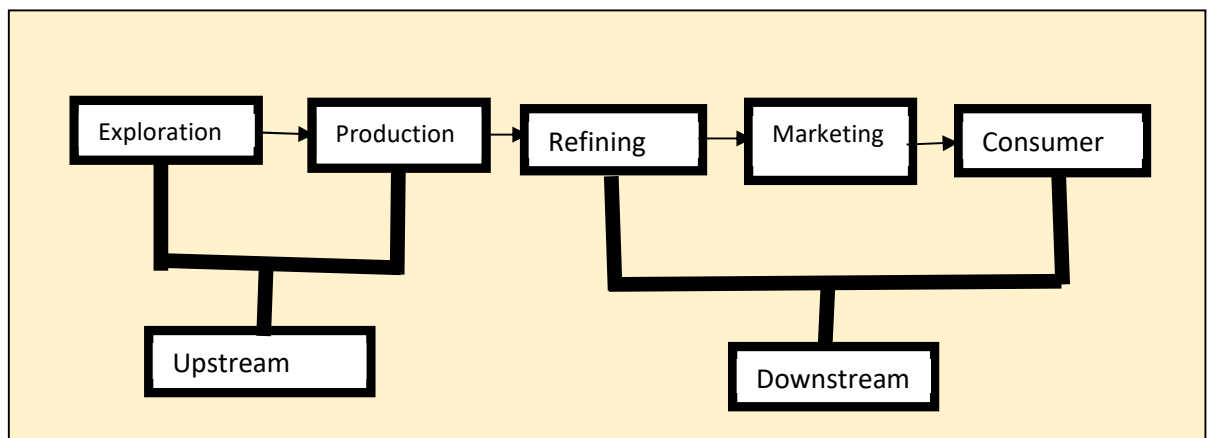


Figure2. 16 Supply Chain of the oil and gas industry, Source; Chima (2007)

As the ever-diminishing profit margin is challenging oil and gas companies, it is natural that they face fierce competition for market share and growth; the drop in oil prices exposes all kinds of inefficiencies throughout the supply chain. In general, there was a lot of talk about how falling oil prices put immense pressure on everyone to do “more with less.” Falling oil prices present a considerable opportunity for utilizing Lean principles (Kristian Kalsing, 2015)

All players along the supply chain to optimize the supply chain activities and streamline the processes to eliminate non-essential, non-value-adding processes and activities need

an integrated action. In the age of Supply Chain Competition (SCC), the form of the competitiveness of the supply chain is affected by three forces the core competence of the supply chain (the force of decision making), the operational mechanism of the supply chain (the force of assistance) and the competitiveness evaluation of the supply chain (the force of maintenance), (Hui & Wen-jie, 2009).

The ‘collaborative paradigm’ in supply chain management regards strategic collaboration as a crucial source of competitive advantage. Collaboration is even more essential when supply chains aim at ensuring simultaneously economic, environmental, safety system, and social performance on a product's total life-cycle basis (Stefan Gold et al., 2009).

2.21 Processes in the Upstream Oil and Gas Sector

Oil and gas developments are evolving from conventional to unconventional resources for onshore and from shallow to deep-water for offshore. Offshore developments are shifting from shallow water areas such as the Middle East, the North Sea, South East Asia, North America, and Australia to deep-water areas like Africa, Brazil, the Gulf of Mexico, and the Arctic.

Arild Moe (2010) asserted that Norway has emerged as a significant oil and gas producer since production on the Continental Shelf commenced in the early 1970s in the North Sea. In 2008, Norway was the world’s fifth-largest net exporter of crude oil. It has also become a major supplier of natural gas in Europe, covering between 20 and 30 percent of total consumption in Germany, the UK, and France. Fields on the Norwegian Continental Shelf are connected with terminals on the European continent and with Great Britain by several pipelines.

Most Norwegian production takes place in the North Sea. During the past decade, the most prominent findings of new resources have come from the Norwegian Sea, off the midsection of the coast of Norway (statoil.com). The country's future oil and gas production will increasingly focus on the northern part of the continental shelf, the Barents Sea. Several minor discoveries have been made, but only one, the gas field Snøhvit (Snow White), discovered in 1984, has been developed so far (Arild Moe, 2010).

Fig 2.17 depicts the Norwegian continental shelf, one of Europe's oil and gas-rich shelves.

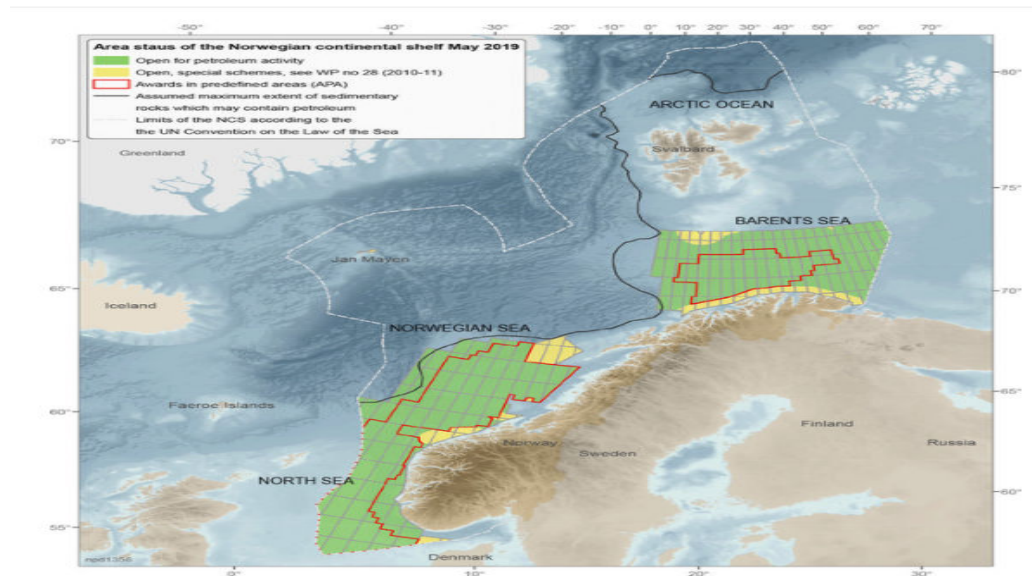


Figure 2.17 the Norwegian continental shelf, Source; NPD, 2009

2.22 Norwegian upstream oil and gas industry

The Norwegian upstream oil and gas industry is a complete cluster of 136,000 employees divided into several sectors: Operators (22,000), Geo & Seismics (4,000), Drill & Well (20,000), and Topside (43,000), Subsea (13,000) and Operations Support (34,000). Sasson & Blomgren, (2011). The value creation from operators and suppliers represents one-third of the Norwegian GDP (2008) (Sasson & Blomgren, 2011).

Practical challenges encountered in the oil and gas activity on the Norwegian continental shelf have given birth to a number of important innovations through close cooperation between operators and suppliers. This has made Norway an attractive location for oil and gas R&D with many international oil and gas companies, Sasson & Blomgren (2011). The existence of a strong national oil company, Statoil, has given the Norwegian oil and gas industry an established local base to pursue R&D and implement new technologies and best practices across the industry. When oil and gas activities began in Norway, the country already possessed an international maritime industry and industrial actors within the fabrication and construction fields (Sasson & Blomgren, 2011).

2.23 Summary

The oil and gas industry is encountering minor to major and, in some cases catastrophic accidents. The industry has been applying all possible measures to transform the industry's safety system, and yet incidents and accidents are still happening irrespective of all these measures. The author of this study argues that business, as usual, where the industry reacts to its safety system, especially when incidents and accidents happen, could not take the industry anywhere. A paradigm shift in handling safety systems is imperative to innovate the industry's safety system by incorporating safety in other business processes.

The oil and gas industry plays a pivotal role in the global energy supply. Ineffectiveness, inefficiency, and non-value-adding activities mainly occurring during incidents and accidents are costing the industry in terms of personal safety, social and economic costs in particular, and the global economy in general.

From literature reviews, it was found that most articles focus on safety compliance. Nothing wrong with achieving compliance, but the issue is compliance is the basics of safety system requirements. The industry needs to innovate its safety system more than safety compliance to spare the most key sector of the global economy from vicious incident accident traps.

The industry's safety investigation in the aftermath of safety incident and accidents predominantly focus on things that went wrong. The industry has been learning from things that went wrong with less emphasis and, unfortunately, with no focus on learning points on things that have gone right.

Any successful business is the combined effort of all stakeholders and key players. The safety system is no different. For an effective safety system in the oil and gas industry, management involvement, responsibility, and engagement are crucial for every employee. The current norm and tendency are to leave safety issues and agenda to the safety department. Safety officers would not bring the change required to cope with the enormous challenges the industry has been facing from safety aspects.

In contemporary competitive business processes, cross-functional collaboration is key to achieving business goals, breaking silo functional organization with communication gaps, and considering business values from the value chain and system synergy. Safety

should be ingrained in every business process instead of seeing safety as an isolated silo segment that would be left to the safety department.

Most safety researchers agree that about 90% of safety incidents and accidents happen due to unsafe acts and about 10% due to unsafe conditions respectively, Sherrat et al., (2015). And yet most academic research endeavors and company efforts focus on unsafe conditions giving less emphasis to unsafe acts and a safety culture.

Chapter Three

3. Research Design and Methodologies

3.1 Research Design

This chapter of the dissertation outlines the basis of the research study. Conceptual and descriptive research methodology would be followed to explore the implementation of continuous safety system improvement through operational excellence methodology and lean thinking in the oil and gas upstream sector with a special focus on Norwegian oil and gas exploration and production.

Primary and secondary data were collected from the operator and service companies that are key players in the Norwegian oil and gas exploration and production sector. For confidentiality, the oil servicing company, called Supplier Y. Supplier Y, is a market leader in North Sea operation that provides oil and gas well drilling and measurement services. In the same manner, the leading operator, Operator X. Operator X, is also the market leader in the North Sea oil and gas exploration and production and the main service client of supplier Y and has already started implementing lean philosophy at the start phase.

The study takes advantage of the synergy effect of operational excellence methodology implementation along the value chain to enhance the effort of Operator X, which has already in the implementation phase with aligning Supplier Y, which has no experience of lean in the overall value chain lean implementation process.

The approach that will be followed for this study will be the oil and gas operator, which has the major operation and market leadership in the North Sea operation will be considered. For confidentiality, this company is hereafter named 'Operator X.' The good thing about operator X is that it has just started implementing lean thinking. Operating companies use various service providers of the very nature of oil and gas exploration and production. These suppliers supply catering, cementing, logging, drilling, mudlogging, drilling fluid, subsea, casing, scaffolding, maintenance, etc.

As there are multiphase of business interaction between Operator Company and the various service providing companies, suppliers, business-to-business relationships,

communication, safety system interaction, value chain visibility, upstream sector-wise work standard applications would be evaluated. The case company selected for this study is an oil and gas drilling service provider, which is also a market leader in the North Sea with drilling and measurement service provision; for the sake of confidentiality, hereafter, the company will be named as 'Supplier Y.' 'Supplier Y' has no experience of implementing lean thinking. Yet, it is the leading service provider for 'operator X'; primary data has been collected from Supplier Y company employees.

Thus, this dissertation research focuses on exploring the safety system of upstream oil and gas and how to improve the positive development using operational excellence methodology continuously. The research explores the current safety state as an integrated value chain and interdependent sector player. It develops a robust safety system from the 'respect for people' philosophy of lean and frontline employees' involvement and engagement.

The accomplishment of lean implementation success, witnessed in the manufacturing industry, could be used as a benchmarking experience to practice it in the oil and gas industry. Lean is a process, people-based system where processes are innovated and streamlined to help people perform their tasks successfully and safely.

A thorough literature review has been done using peer-reviewed journal articles from high-impact factor journals. Numerous literature on the theory and practices of Lean production (LP) is available in various publications and conferences (Jasti & Kodali 2015).

Journal articles search was limited to articles related to the safety system and lean thinking published on Emerald Online, Science Direct, SpringerLink, and Taylor and Francis publication portals. The researcher has chosen 1988 as the starting year as Krafcik (1988) introduced the concept of lean for the first time in the article 'Triumph of the lean production system'.

For the search screening, the researcher has used the following keywords: safety system, workplace injuries, lean production, lean manufacturing, lean management, lean safety, lean supply chain, lean culture, lean enterprise, Just-in-time, lean thinking, lean philosophy, Toyota Production System, safety culture, workplace safety, etc. Please refer to Fig 3.2 for the article's screening process.

3.2 Research Framework

The research framework is designed based on continuous improvement, respect for people, and industry competitiveness through waste elimination and value creation from the perspective of customer value and employees' well-being and safety in the workplace.

Lean philosophy, which has been practiced and found to be a winning business improvement methodology in the manufacturing and healthcare sectors, is the leading research topic to be explored from the context of the oil and gas sector safety system.

The research framework of the dissertation is designed based on fundamental principles and techniques of lean philosophy:

- True North: organization's top management has the duty of setting business direction in terms of the organization's product and service provision and setting long-term and short-term strategy, using strategy deployment (hoshin kanri), Liker JK & Convis GL (2012), and aligning business goals and objectives to the organization true north values. In the diamond model, Liker JK & Convis GL (2012) explains how an organization builds a culture of continuous improvement through learning to live true north values, coaching and developing employees (learning cycles), daily management(daily kaizen), creating true north vision.
- Applications of lean tools and techniques, so that to be able to see oil and gas activity process wastes and problems, Shook and Rother (1999). Tools such as 5S, Error Proofing, Gemba, Heijunka, Kanban, JIT, Root cause analysis, standardized work, Andon, Bottleneck analysis, visual control, 7 deadly process wastes, Ohno (1988).
- Lean practical problem-solving methodology. As profound challenges face the oil and gas industry day, practical problem solving is imperative. The frontline employees are the ones who know the work better than anyone else does. Thus, they should be empowered to do the job and improve it. Tools like PDCA, Deming, (1986) and A3, Shook and Rother (1999), Toyota KATA, Rother (2000).

- Organizational clarity: organizational Clarity is the most important parameter that gives an organization to stay focused and prioritize what is essential in winning the market competition and using the internal and external resources and capability. It is customary to see oil and gas companies take action of cost-cutting, layoff, and shelving projects in a time of low crude oil prices. Thus, oil and gas companies need to communicate organizational vision, purpose, and performance (Martin, 2018).
- One of the common mistakes in lean implementation is the sub-optimization of the process. Peter Senge (2006) conceptualizes organizations as dynamic systems in states of continuous adaptation and improvement.
- One of the most powerful competitive advantages organizations depend on is their workforce. Disengaged workforces are costing the global economy quite a lot. Only 13% of employees worldwide are engaged at work, according to Gallup's new 142-country study on the state of the Global Workplace, Gallup (2012)
- Value Stream: mapping the customer value creation process from concept to launch, order to delivery (information flow), and raw material to end-user (material flow), Womack & Jones (1996). To do the value stream mapping, it is imperative to grasp the current state by doing the 'Gemba' walk; as lean practitioners practice it, 'go and see.' These would enable us to see the current state and the product and service provision gap based on the customer perspective. Walking through the series of activities, one would identify the value-added and non-value-added activities the customer is willing to pay for. Based on the current state and customer value perspective, the future state could be mapped by identifying any of the activities that do not add value for the customer would be eliminated.
- People-based safety. One of the two pillars of lean philosophy is respect for people. As the key organization's capital, human capital, employees are the core of an organization's competitive advantage. Thus integrating safety in every activity, the organization does and making safety a value brings employees to a shared vision and take responsibility to own safety and act

engagingly to keep the workplace free of injuries and minimize incidents that could develop into accidents.

- Respect for people. One of the two pillars of lean philosophy is ‘Respect for people’ people are the primary workforces to win or fail an organization. Engaged and actively participating workforces are innovating work processes and improving workplace safety systems. Coetzee et al. (2019) list that respect for people could be expressed in terms of ‘teamwork, develop and challenge people, motivation, develop people as problem-solvers, safety, remove waste and display people’s capabilities.
- Safety I: That as few things as possible go wrong
- Safety-II: That as many things as possible go right, Hollnagel et al., (2015)

Fig 3.1 below illustrates the concept flow of the research framework.



Figure 3.1 Research Framework

3.3 Research Methodologies

Mixed research methodologies will be used to use the benefits of each. Collecting data from multiple sources would enable us to minimize the bias and limitations of a single method Maxwell, (1996); The Pell Institute, (2017). The descriptive and conceptual methodology will be applied to evaluate, assess, benchmark, and develop a continuous safety system improvement model that fits the context

Different kinds of data will be collected: quantitative, qualitative, primary, and secondary data from Supplier Y and Operator X companies. Moreover, data from oil and gas industry best practices, industry manuals, and annual safety reports, regulatory bodies' directives, regulations, etc.

3.4 Literature Review

In the literature review part of the research, various articles, periodicals, proceedings, books, magazines, newsletters, newspapers, websites, and other materials were reviewed to assess the state-of-the-art of safety system, continuous improvement in safety, lean application in business process improvement in various industries in general and oil and gas industry in particular.

Based on literature review and benchmarking of lean thinking Pioneers such as manufacturing and healthcare industries, a safety system continuous improvement model for oil and gas upstream context will be developed.

Supplier Y will be closely analyzed to explore its current safety practice and opportunities for continuous improvement. The lean respect for people and a people-based safety system are the two core ideas to be used in this research to conceptualize Continuous safety system improvement for operators, suppliers, service providers, and all stakeholders and players alike. The competitive business advantage of a safe workplace and the overall synergy impact with respect to Operator X, supplier Y, and other players along the value chain. To this end, the safety performance, injury rate, business activity level and hazard exposure, types of activity, body part the most injured, leading and lagging incident indicators of Operator X for the years ranging from 2009 to 2018 will be closely analyzed.

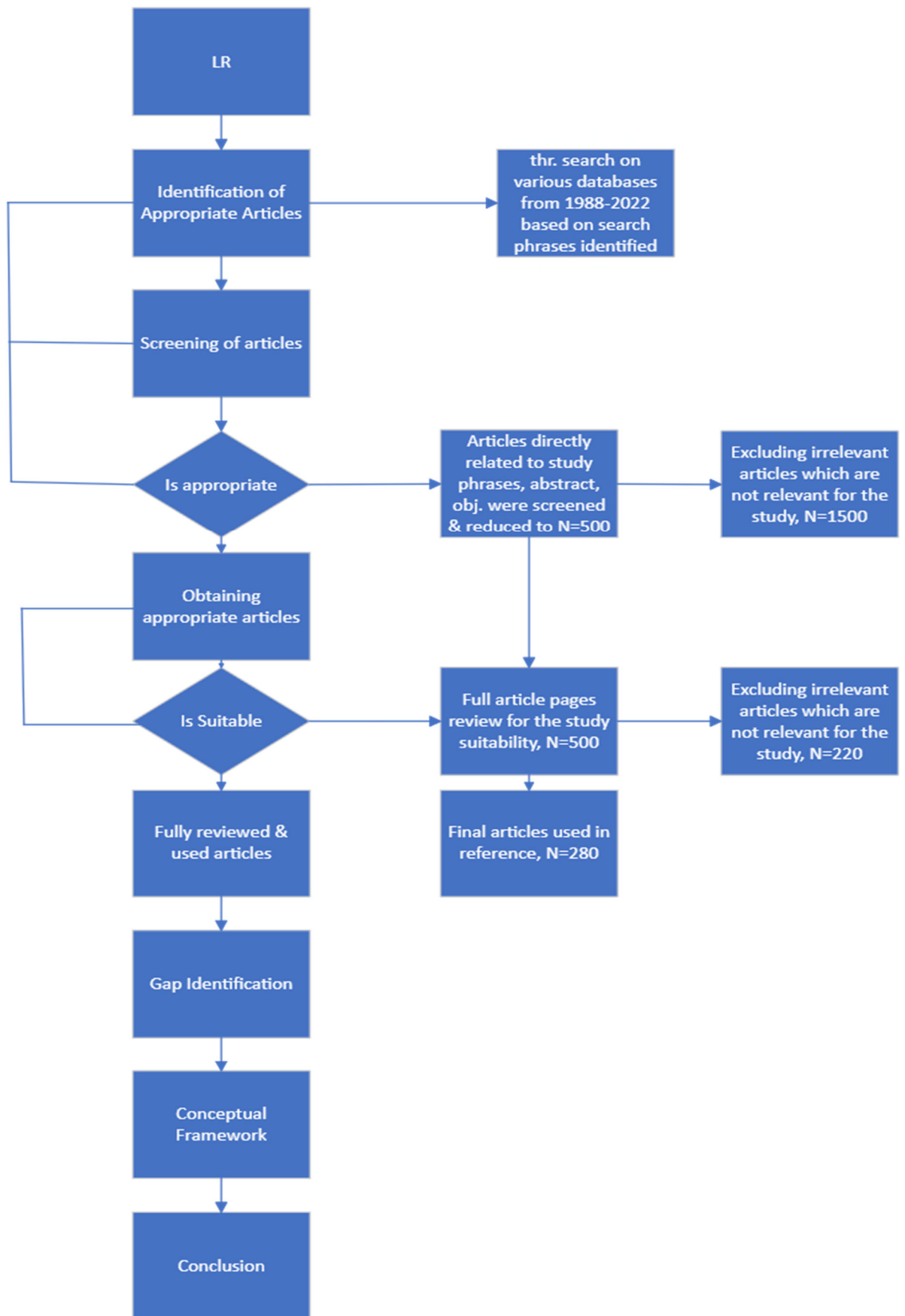


Figure 3.2 Articles screening process

3.5 Primary and Secondary Data

Primary and Secondary data will be collected from Supplier Y and Operator X. As mentioned earlier, Operator X has already started the first phase of implementing the lean philosophy. Secondary data for the last ten years (2009-2018) has been collected, so that to include the oil price boom and bust in the form of injury rate, total annual hours worked, injury reports, injury investigations, types of activity, a company working standard documents, governing documents, best practice documents will be analyzed to evaluate operator's X injury frequency rate as an indication for the sectors performance compared to other industries injury rate.

Likewise, primary data from supplier Y employees in the form of a questionnaire will be collected to include the practical hands-on experience of Supplier Y company employees in workplace safety practices. The secondary data will include annual financial reports, HSE reports, safety reports, Standard working instructions, governing documents, best practice documents, published articles, books, industry standards, manuals, lean enterprise, etc. The secondary data collected from Operator X will be used to evaluate the continuous safety system improvement model, which will be developed as part of this dissertation work.

The main types of data source where this research is based is primary and secondary data. Secondary data from sources like published articles, books, industry standards, manuals, lean enterprise, selected companies' annual safety reports, etc.

3.5.1 Tools and Methods

Various tools and methods will be used to analyze collected data and develop a continuous safety system improvement model. Machine learning software such as Random Forest (RF) algorithm, MS-Excel, etc., will be used. The Continuous safety system improvement model would be a continuous safety system model based on the philosophy of respect for people, employee engagement, and frontline employees' involvement in business safety system continuous improvement for oil and gas upstream sector activity, which is a contextual model tailored for oil and gas activity, benchmarking the famous Toyota Production System (TPS) and lean philosophy.

In addition to the above tools and methods, lean practical problem-solving tools such as PDCA, error proofing, 5S, 5Why, A3, etc., will be used.

3.6 Chapter Summary

Journal articles search was limited to articles related to the safety system and lean thinking published on Emerald Online, Science Direct, SpringerLink, and Taylor and Francis publication portals. The researcher has chosen 1988 as the starting year as Krafcik (1988) introduced the concept of lean for the first time in the article ‘Triumph of the lean production system’. Articles were screened using screening processes shown in Fig. 3.2, and 280 articles were considered for reference.

Keywords used in articles screening were Safety system, lean thinking, continuous improvement, ‘respect for people, people-based safety, safety compliance, workplace injuries, and machine learning.

Primary and secondary data were collected. Primary data were collected from Supplier Y Company, and Secondary data was collected from Operator X Company. Machine learning Random Forest algorithm was used to predict injury rate using secondary data from Operator X.

Chapter Four

4. Qualitative Data Analysis for Oil and Gas Industry Safety System

4.1 Introduction

International Labor Organization, ILO estimates that some 2.3 million women and men worldwide are exposed to work-related accidents or diseases yearly; this corresponds to over 6000 deaths daily. Worldwide, around 340 million occupational accidents and 160 million victims of work-related illnesses annually. The ILO updates these estimates at intervals, and the updates indicate an increase in accidents and ill health (ILO.org).

Some of the major findings in the ILO's latest statistical data on occupational accidents and diseases and work-related deaths on a worldwide level include the following: Diseases related to work cause the most deaths among workers. Hazardous substances alone are estimated to cause 651,279 deaths a year. Younger and older workers are particularly vulnerable. The ageing population in developed countries means that an increasing number of older persons are working and need special consideration (ILO.org).

Studies from the North Sea and globally show minor-to-major operational accidents/incidents in the petroleum industry. The root cause of incidents upstream and downstream is unsafe acts and conditions. To reduce the risk level of fatal and non-fatal injuries, petroleum safety authorities emphasized implementing carefully designed safety management strategies. The primary step is to prepare a plan that identifies all safety hazards and risks, assessed, analyzed, and mitigated through a continuous process (EU 2012; Bye et al., 2018).

Lean thinking is applied in the health care and manufacturing industries. This research addresses how offshore operational safety is improved through lean thinking, where upstream work processes are streamlined to eliminate process wastes, improve workplace safety practices, hazard identifications, employees engagement, top management leadership role in safety, supervisors, and frontline employees' involvement in operation safety continuous improvement. The overall results are improved productivity, minimized cost, reduced non-productive time, and increased customer and employee value by creating a safe working environment.

The Swiss cheese model could be an illustrative model that shows how different factors could contribute to the causations of accidents, Reason (1990). This is also evident in offshore oil and gas activities, where there are many factors that jeopardize the safety of the workforce, assets, and the environment in general.

The very reason offshore structures should work under extreme weather conditions, the structural and safety-critical equipment should stay intact and work properly for the whole part of the installation's life cycle is due to the high cost of incidents and accidents to assets and people and the environment. It is important to follow standards, codes, guidelines, and best practices for any structural design and construction works to ensure sustainable structural integrity. Sustainability is also the primary concern in the oil and gas industry, Zhang et al. (2019). Figure 4.1 outlines the relationship between offshore relevant international standards (ISO 10418:2019). The standards describe the lifecycle phases of engineered works (Concept, Design, Construction, Operations and Maintenance, and Termination) and safety and control issues during offshore operation.

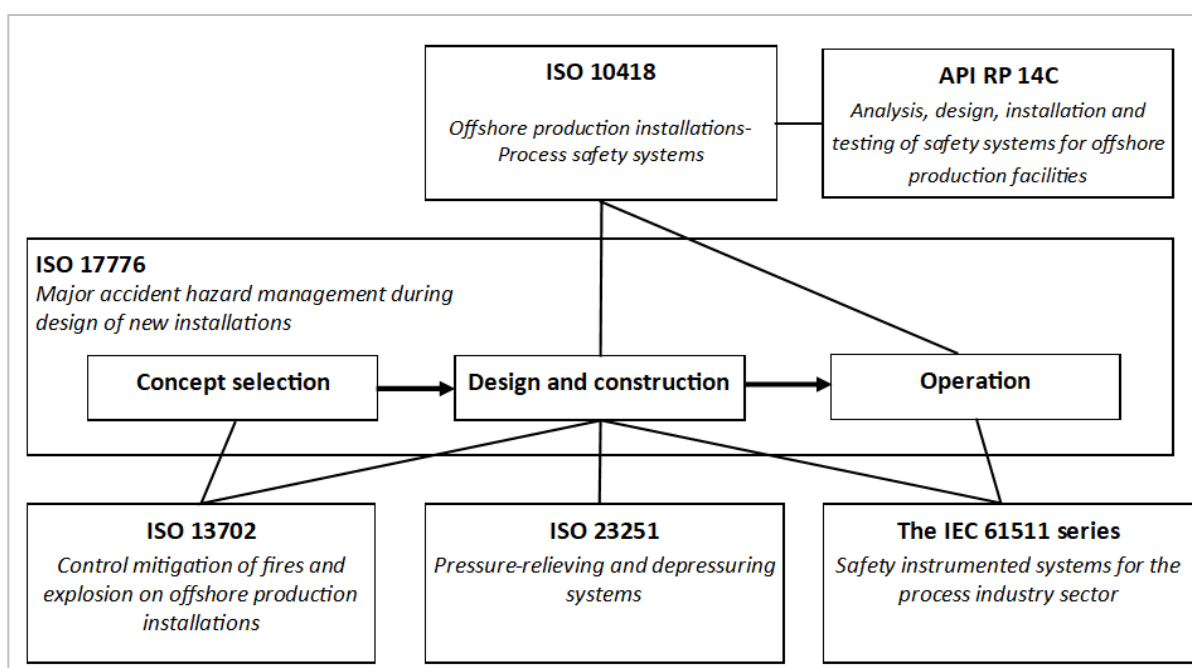


Figure 4.1: Relationship between offshore relevant standards (ISO 10418:2019).

Based on best practices and international standards, the NORSOK D10 standards are designed for well and operation to be applied on the North Sea continental shelf. NORSOK D10 standard (Well integrity in drilling and well operations) is the most practiced standard in upstream oil and gas activities.

NORSK D10 defines well integrity as the application of three solutions to reduce the risk level of an undesired leak during the life of the well, which increases the maximum productivity of the reservoir as well as avoids loss of natural resources and a safe environment, NORSOK D10. This research focuses on organizational solutions considering people-based safety; people are solutions providers, not problems, parallel to lean thinking and respect for people.

Timely and proper incidents, accidents reporting, and recording would enhance learning and applying continuous improvement and mitigation measures. However, occupational injuries, accidents, and environmental degradation issues reported during petroleum works lack consistency (Ahmad et al., 2016). This is especially the case if employees fear reprisal due to reporting incidents.

Figure 4.2 shows a typical best practice guidance for offshore lifecycle operations, which includes exploration, development, production, and decommissioning phases, European Commission, (2019). As illustrated, the activities include design, risk assessment, and management, which must follow the recommended practices under the mentioned activity guidelines. More detailed activities concerning operational phases, both testing and acceptance criteria, are documented in NORSOK D-10. However, the process requires continuous follow-up, inspection, remedial actions, and standards updating. These are the key to prolonging the well's life cycle time, extracting efficient energy with cost-effective investment, and improving HSE.

For instance, the operation investment is without return value during decommissioning phases. However, continuous technological and innovative methods and reliable standards, which suits best for this operation, can reduce the operational costs of plug and abandon (P&A) and improve long-term integrity, a key factor for a safe environment. This could promote sustainability by keeping the environment in good order and balancing the ecosystem.

Hovda et al. (2008); Rehm (2013) argue that the oil and gas supply and demand imbalances coupled with rare discoveries have led the industry to explore wildcat projects in arctic and deep-water areas operationally challenging and impact the safety conditions of the workforce. Since the drilling rig rate is expensive, the visible and non-visible nonproductive times cost the oil industry a lot. The root cause of the NPT(Non-productive time) is associated with, among others, kick, lost circulation, stuck pipe, drill string failures, waiting for supplies, waiting on weather, waiting on service providers fixing problems, and wellbore instability, activity stop due to safety-related incidents.

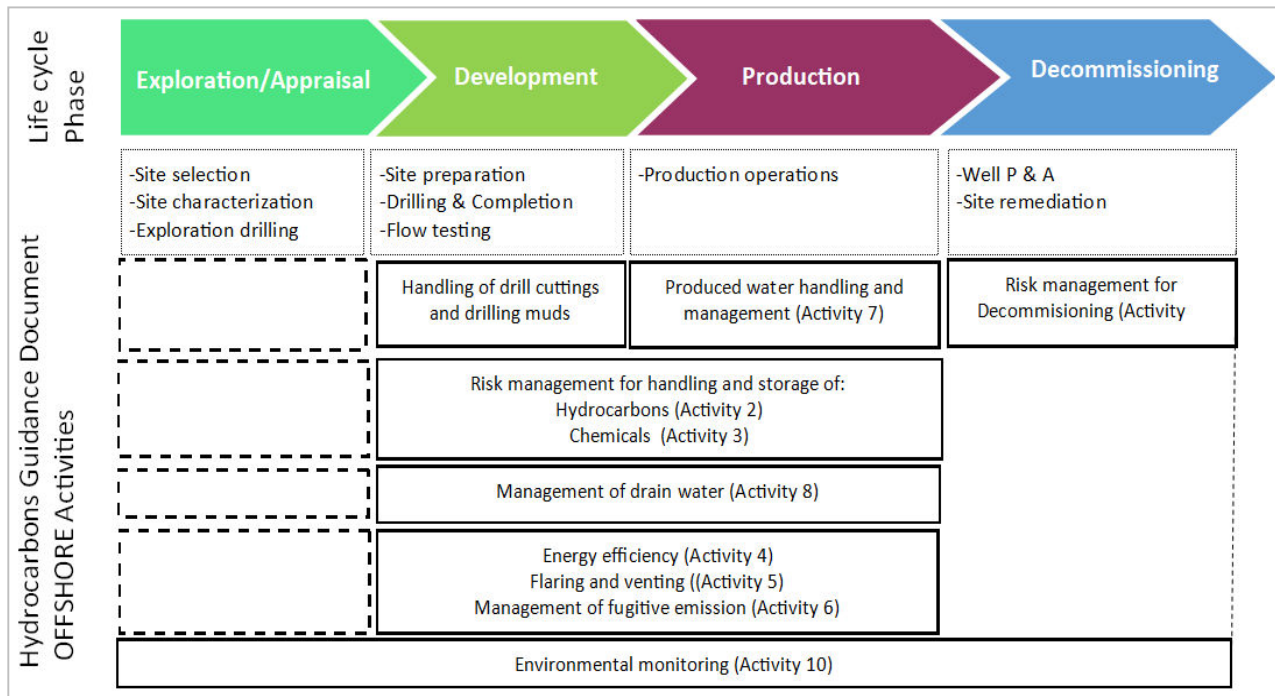


Figure 4.2 offshore lifecycle and activities; Source: Best Available Techniques Guidance Document on upstream hydrocarbon exploration and production, European commission (2019).

Kick is an influx of hydrocarbon to the wellbore. It occurs when the well pressure is lower than the reservoir pressure. Controlling kick with properly designed control procedures prevents undesired surface blowout. For instance, in 1988, the Piper alpha blowout incidence in the North Sea cost 167 deaths, several serious injuries, and billions of dollars Cullen, (1990). In 2010, the Deep-water Horizon blowout incident in the Gulf of Mexico resulted in the largest oil spill in the oil and gas industry, Jernelöv, (2010). The accident costs 11 human life, environmental pollution, and loss of enormous resources, as shown in Figure 4.3. The root cause of the incident was eight fundamental technical problems. Investigators indicated the operational gap between BP’s operation with respect to NORSOK D-010 and API standards. Moreover, the standards do not clearly define the negative-pressure test procedure and acceptance criteria. This indicates the need to improve guidelines based on best practices (Gokulakrishanan & Belayneh, 2018, Yeshitila et al., 2021).



Figure 4.3: Blowout and its consequences Macondo, DHSG, 2011.

Pickrell & Bea (1997) indicated that humans and organizations are the key factors for the safety of offshore/onshore structures engineering works such as design, construction, operation, maintenance, and decommissioning. The human factor involved continuous real-time safety management during operations and developing an appropriate Safety Management Assessment to Sysprolonginglong the structures' life (Pickrell & Bea, 1997).

According to Pate-Cornell, and Bea (1998), the incident in the Piper Alfa attributed to human and organizational factors are involving hazardous technology failures, which include poor design guidelines and design practices, mistakes in the management of the personnel on board vs. safety, and as well as errors in decision/action, and lacking attention to inspection and maintenance operations. One continuous safety improvement practice must be designing a safety system to accommodate human errors.

The structural integrity of platforms might worsen due to physical damages such as corrosion and mechanical impacts. Implementing Safety Management Assessment System would reduce the risk of structural failure and accidents, reducing NPT wastes related to maintenance and undesired expenditure. Ratnayake & Markeset (2010) argue that Oil and Gas (O&G) platforms in the North Sea face aging problems as many installations have matured and are approaching their design lifetime. To exemplify their argument, the authors considered Flowline degradation due to corrosion and erosion. The deterioration of a flowline may increase the risk of leakages, ruptures, etc., leading to severe HSE (health, safety, and environmental) and financial consequences. As exemplified earlier and documented in several papers, occupational injuries, accidents,

and environmental degradation occurred during petroleum works. This also occurs in the upstream (exploration and production sector) and downstream (petrochemical industries).

4.2 Norwegian oil and gas sector activities

For the Norwegian sector, since the blowout incident in the Piper alpha, the petroleum safety authority of Norway has been working hard to reduce the risk level of the HSE issue. The HSE standard defines health, safety, and environment (HSE) concerning construction and installation- activities on- and offshore, including marine installation activities. The standard defines a project process through which all parties focus on risk, activity, responsibility, systematization, and communication/collaboration (RNNP, 2019).

However, the yearly Risk level Norwegian petroleum activities report from operation in the Norwegian Continental Shelf (NCS) indicated injuries to people; well control incident, damages to structures, and marine systems, leak from wells, and incident on ship collision and helicopter as well. Figure 4.4 shows the number of incidents recorded from 2000-2017 on the exploration drilling and production drilling wells, RNNP (2019). It is evident that the number of well control incidents on the production well exhibited higher than the exploration wells due to the drilling depth and the experiencing high reservoir pressure. The real root cause of the incidents is not explicitly reported in detail.

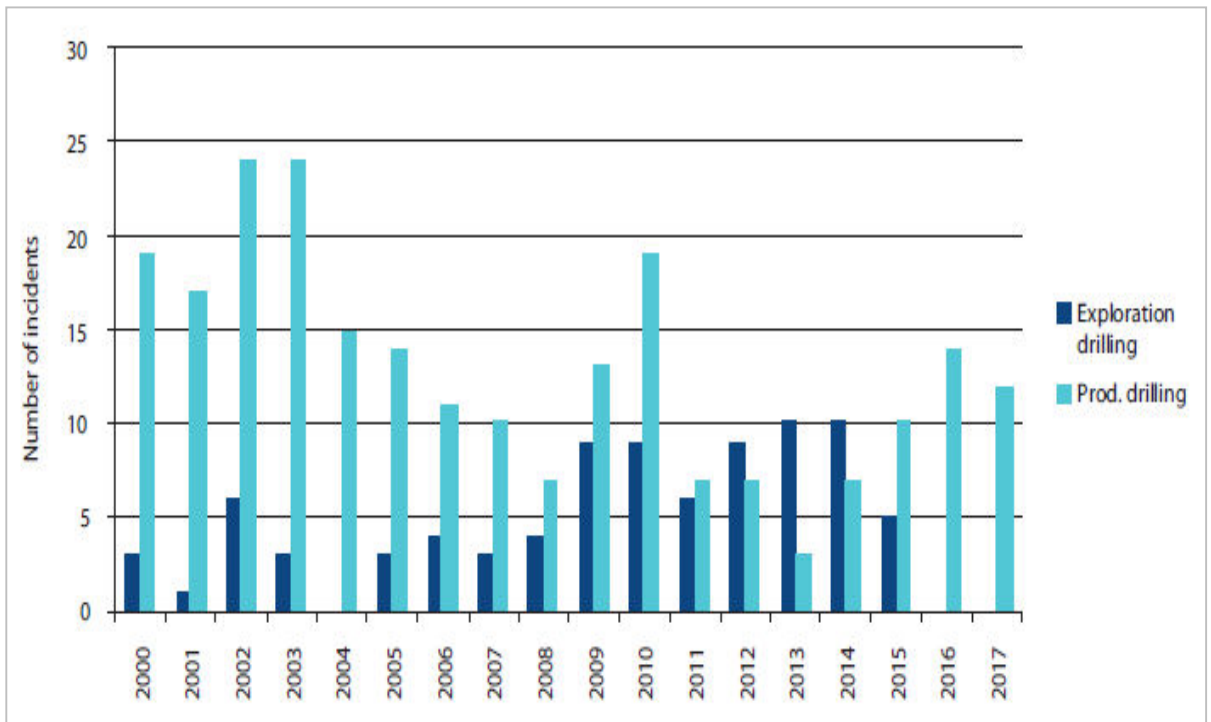


Figure 4.4 Number of well control incidents in exploration and production drilling, 2000-2017 RNNP (2019)

The RNNP has calculated the total indicators for major accidents based on the incident frequency and the potential of the incidents to cause loss of life. Figure 4.5 displays the results of the relative risk indicator for production facilities per year along with the three-year rolling average, RNNP (2019).

The annual indicators show a large variations. It is reduced when displaying the three-year rolling average, which clarifies the long-term trend. During the three years rolling calculation, the working hours are used for normalising against activity level. Figure 4.5 shows that the total indicator for 2018 is the lowest for the entire period, RNNP (2019). The main reason could be fewer activities due to the downturn period. However, the active wells and activities still showed a minor risk level.

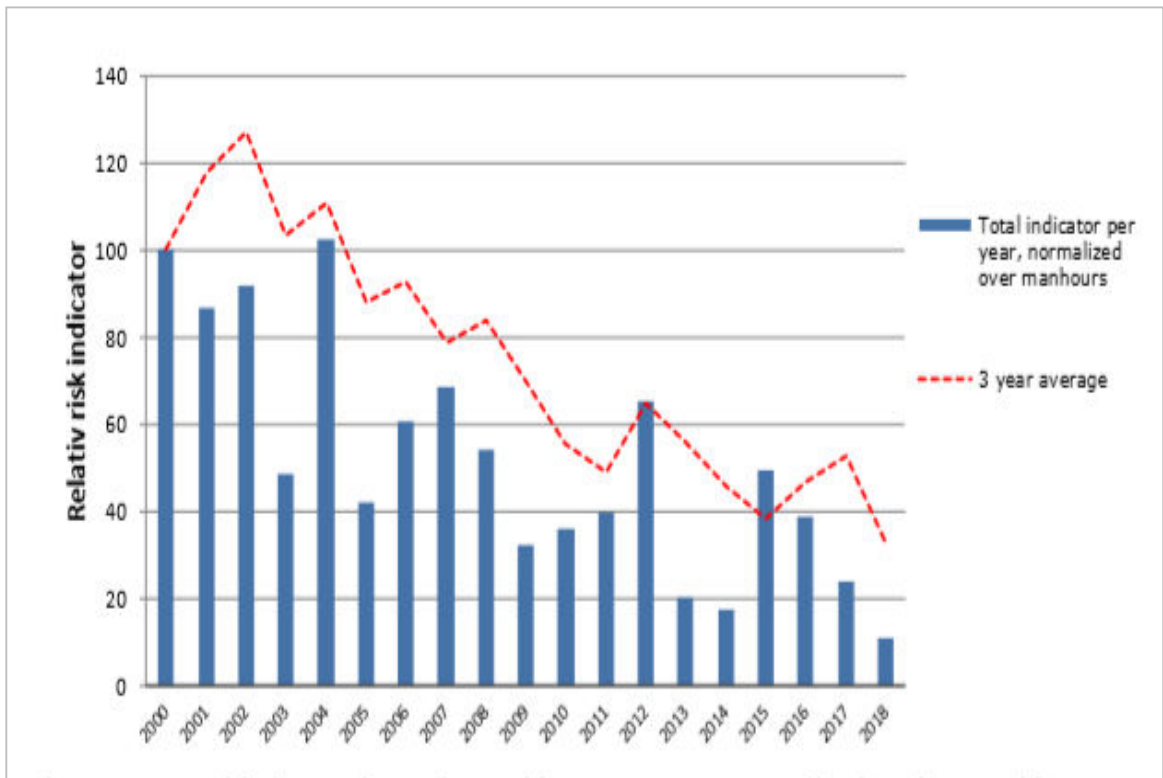


Figure 4.5: Total indicator for major incidents per year, normalized against working hours, annual values of and three year rolling average (2000-2018). RNNP (2019)

4.3 Lean Thinking and safety in upstream O&G

Currently, the oil and gas industry is working to develop methods and technologies to improve operational performance, minimize HSE (Health, Safety and Environmental) risks, reduce non-productive time, enhance productivity and hence minimize operational costs and damage to assets and injuries to workforce.

Construction is like manufacturing cars, which use predesigned workflow processes to achieve the desired final product. In recent years, the application of Lean thinking in manufacturing, the auto industry, and health care has shown impressive results in waste management, compelling performances, problem-solving, and customer value addition. This study, therefore, would address the application of the lean philosophy of respect for people and workforce engagement and involvement in business overall performance that can be expressed in triple-bottom-line gain in the area of economic, environmental, personnel safety, and social benefits in the oil and gas industry, with a specific focus in offshore drilling and production sector.

The leading oil and gas operator on the Norwegian continental shelf, Equinor has started implementing lean philosophy, which has acquired popularity in the manufacturing and health care industries (equinor.com).

According to Equinor is a way of working and a culture of continuous improvement in every aspect of the company’s portfolios. Equinor is applying Lean thinking for the business model and performance management, Fig 4.6, (equinor.com). The Lean process requires continuous improvement during each phase of exploration and production processes. The main goal is to improve safety practices and sustainable and profitable operations. The critical elements in the Lean approach are understanding the external and internal customer needs and requirements; optimizing product or service value while reducing non-value-added activity; and engaging the organization in identifying and realizing improvement opportunities. Identifying risks and implementing them correctly is part of performance management (equinor.no).

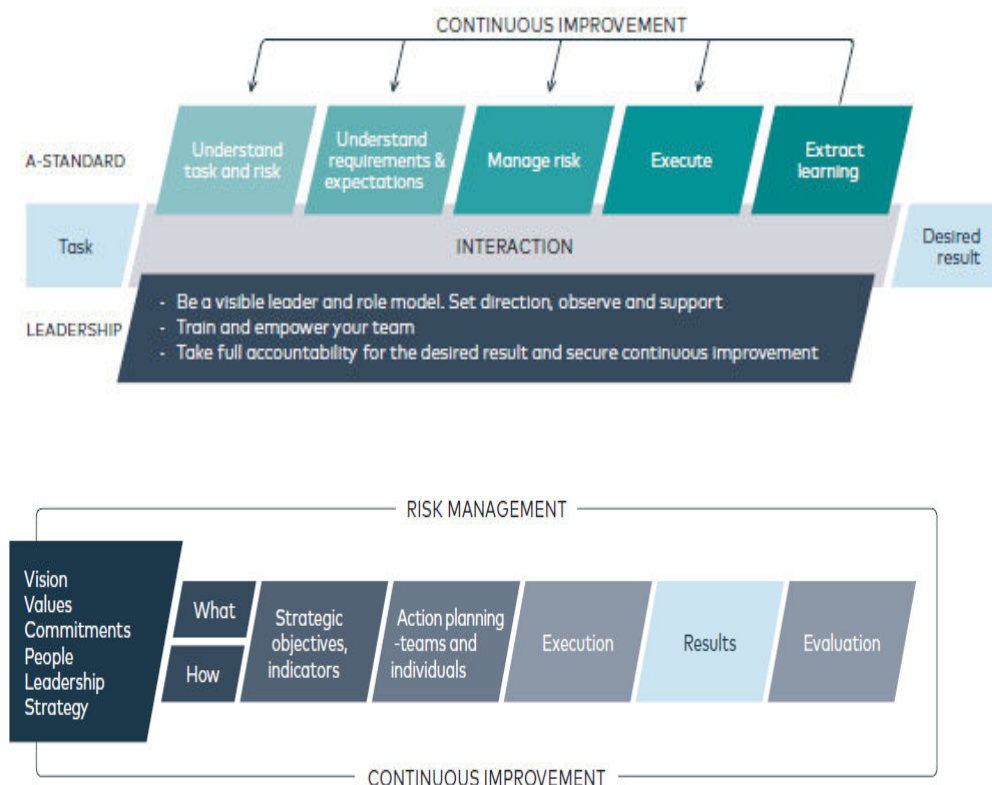


Figure 4.6: Illustrations Equinor’s performance management, (equinor.no).

4.3.1 Lean management for oil and gas

The primary objective of lean management is the elimination of waste. The concept originated from the Toyota Production System (TPS). For this, Taiichi Ohno was the first to establish efficient work processes. During different phases of petroleum engineering work, wastes must be identified and continuously removed by optimizing and updating the work process. The eight types of waste, plus the author of this study would like to add safety incidents, lost time on injury, etc. as the Ninth waste, which need to be eliminated are Defects, Overproduction, Waiting, Not Utilizing people's Talent, Transportation, Inventory, Motion, and Over-processing, Taiichi Ohno (1988).

Researchers from the Massachusetts Institute of Technology (MIT) have identified the success behind Toyota's competitive advantage, Holweg (2007), and realized that the company's working culture and management system under the umbrella of TPS was the catalyzing factor that resulted in the best performance in the auto industry, and finally coined the production system as Lean production, Womack et al. (1990).

Gemba walk is the most appropriate tool to identify waste (Muda). The Gemba walk is a technique that allows observing different processes occurrences in action and where wasteful activities appear, and from the context of safety to hunt safety hazards. The Five-whys and the A3 report are also lean tools used to investigate the root cause analysis and problem-solving. The Five-why's, as its name implies, comprises five "why" questions, while the A3 is a bit more complicated process that encourages cross-organizational knowledge sharing.

The core philosophy and two pillars of lean thinking are continuous improvement and respect for people. One widespread lean practice for achieving continuous improvement is through the Kaizen event. Kaizen is a Japanese word that translates as 'change for the better.' From the point of view of a safety system, safety is not the absence of an accident. Thus, companies must continuously improve their safety system, learning from the positive safety development, even when there are no accidents.

4.3.2 The Eight Types of Waste in oil and gas Exploration & Production

In Lean management, the eight wastes (Muda) are the basic concepts that need to be identified to optimize resources and increase profitability. The oil and gas industry has been in a downturn where profit margins are ever diminished, various costs surge from time to time, and access to new reserves is becoming challenging. McKinsey & company (2015); Favilla et al. (2012) pointed out that conventional oil and gas well delivery accounts for 40 percent to 50 percent of the whole activities, Fig 4.7, of the capital spending for exploration and production. Thus, it is imperative to streamline the oil and gas exploration and production processes to minimize and eliminate non-value-adding process wastes.

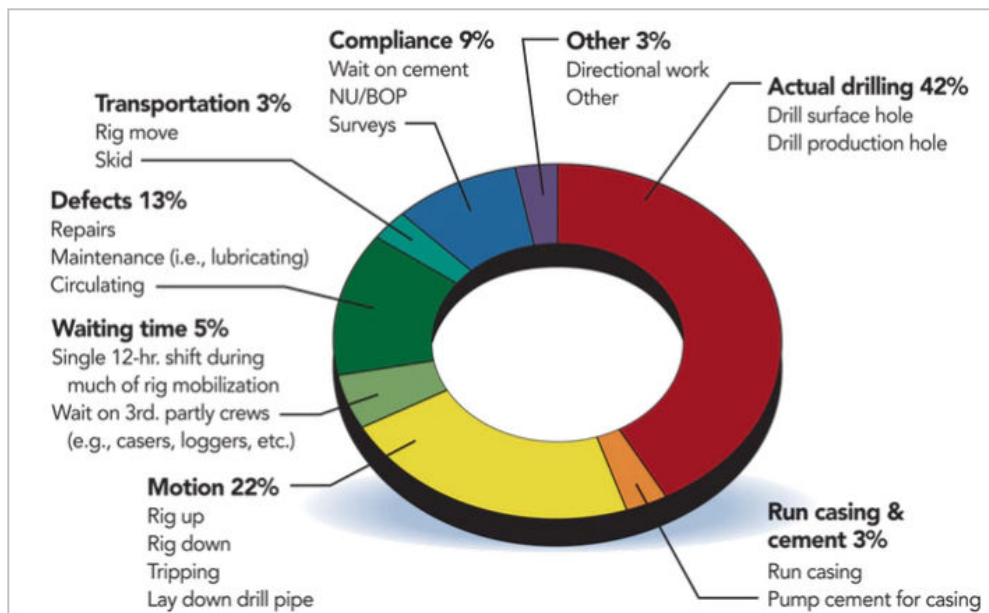


Figure 4.7: Break down of rig activities categorized by waste, Favilla et al. (2012)

The following list discusses each kind of process waste from offshore drilling and production perspectives.

- **Transportation:** Among the challenges in upstream offshore oil and gas activities is the difficulty of supplying various supplies for the offshore activities. The remoteness and harsh weather condition make it a daunting task to deliver supplies without delays.

In lean thinking, transportation is among the eight wastes. The longer the time spent on transportation, the higher the total cost. Thus, it is in the best interest of the overall business value chain to reduce transportation time, as this, from the perspective of lean thinking, does not add value. Supply chain visibility, integrated drilling approach, and collaboration of players along the value chain is best practice in reducing delays in equipment and material supplies and total costs.

Figure 4.7 indicated that transportation was associated with rig move, and skid accounts for 3%. Driving out non-productivity times and non-value-adding activities is a principle of lean thinking.

- **Inventory** Offshore remote exploration and production have imposed various challenges on the oil and gas industry, Favilla et al. (2012). One of these challenges is continuously supplying offshore drilling and production installations with workforces, equipment, tools, spare parts, and food. Some of the inventory items in conventional drilling processes are: drill pipes, drill bits, drill collars, heavy-weight drill pipes and collars, casings, liners, drilling fluid, cement, barite, lost circulation materials, various chemicals, spare parts, and accessories for Mud Pumps, blow out preventers, drill line, motors, engines, valves, surface equipment, living quarter related food items and other related stuff. Helicopters and special vessels are used as means of supplying items. In lean thinking, inventory waste is among the wastes. The inventory holding cost, limitation, and shortage of space in offshore drilling installation further complicate the matter.
- **Motion.** Motion wastes are unnecessary movement by people working the job. A working environment design using the science of Ergonomics and lean work process streamlining would minimize non-value-adding employee motions and reduce the risk and negative impact on the safety and health of employees that could be caused by poor working environment design. People need unnecessary movement to obtain information by walking up and down the rig deck, moving between far-placed working stations for material, spare parts, and other supplies, traveling to various offices to deliver papers, etc., is how motion wastes are expressed. As shown in figure 4.7, the waste associated with motion accounts for up to 22%. The main elements are rig up/down, tripping, and lying down. Continuous development of rig and appropriate design reduces undesired motion-related wastes. For instance, to reduce motion-based wastes, mitigating

vibration through design and BHA control elements (shock absorber, anti-stick slip tools) reduce the off bottom, improve drilling efficiency, and reduce tripping as well as bit/BHA damage. This, as a result, reduces NPT and operational costs.

- **Waiting:** Waiting is one of the most frequently happening wastes in offshore oil and gas drilling; where there could be: waiting on an order, waiting on service company crew and equipment, lost circulation, fishing, work on stuck pipe, mud conditioning, waiting on weather, rig repair—waiting for goods to be delivered. The most significant cost components in well delivery are attributed to the rig rate and service and equipment rentals, typically costing between 50-75% of the total well cost. These components are both time-dependent and a function of prevailing service market demand. Conventional offshore drilling is performed as a sequential activity where one phase of activity is finished to start the next operation. For example, these are the main sequential activities: drilling-wireline-casing-cementing, etc.
- Moreover, waiting could happen while waiting for a decision and further information from the town on how to proceed on some critical issues. As shown in Figure 11, waiting time on rig activities indicated about 5% waste, which is associated with a single 12-hr shift, shift during much of rig mobilization, and wait on third party crew (e.g., Mudlogger, etc.). Moreover, waiting on cement, NU/BOP, and Surveys account for about 9% of waste.
- **Overproduction:** Lean practitioners consider overproduction as the ‘deadliest’ waste of all as it causes other wastes, such as inventory, defect, transportation, motion, overload to employees and creates unsafe conditions, and overload the overall production system etc. In the offshore oil and gas drilling context, overproduction could be expressed in the form of producing more information than needed. One visible overproduction in offshore drilling is various players in the value chain producing the exact deliverables and weakly collaborated players in various service provisions. Another instance of overproduction is where offshore employees are asked to daily report the same safety observation stop card to various parties.
- **Over-processing:** Over-processing is exemplified in forms of processing information beyond the requirement, over-engineering. In offshore drilling,

over-processing could be revealed as long meetings, too many email exchanges, reworks due to changes in deliverables, etc.

- **Defects:** Most North-sea offshore oil and gas installations are aging and liable for defects due to corrosion and material fatigue. Defects and rework lead to unnecessary effort and misappropriation of resources that could have been invested in value-adding activities. In oil and gas projects' environments where several activities are undertaken concurrently, rework can occur from errors, omissions, failures, damage, and change orders, Wilson & Odesola (2017).
- **Waste of underutilized people:** Refers to more people involved in a job than necessary, not involving the associates in process improvement, not leveraging the potential individual to the fullest, not using the creative brainpower of employees, not giving the right assignment/work, uneven work distribution/load balancing, and missed chance of not getting the input from employees, (Wahab et al., 2013).
- **Waste of Safety Incidents** (Author's perspective): Safety incidents cancel all the productivity and quality efforts achieved through time. Safety incidents are usually followed by activities that demand organizational time that otherwise should have been used for value add activities.

4.3.3 Lean in Upstream E & P sector

Lean drilling applies the principles and embedded cultural philosophy of lean manufacturing in all activities and phases of drilling, completion, and production processes. The process streamlines all activities bypassing the conventional silo functions.

Table 4.1 summarizes some lean applications in manufacturing and drilling engineering. The National Institute of Standards and Technology (NIST) Manufacturing Extension Partnership surveyed forty clients who had implemented Lean Manufacturing, Kilpatrick (2003). The survey results showed that lean manufacturing reduced (time, Work process inventory, and space utilization) and increased productivity and quality significantly.

According to De Wardt & Company 2017, correctly applied lean drilling could improve performance, including halving time using 30% cost reduction. Similarly, lean drilling could lead to a 75% reduction in space utilization, promoting the industry's safety

practice. The upstream oil and gas sector is known for operating in an offshore environment where Space utilization is always an issue.

Table 4.1: Application of lean thinking in manufacturing and drilling engineering works

Operation	Method	Improvement	Authors
Drilling			
Rig movement	Lean drilling	30%	De Wardt & company, 2017.
Rig move cycle	Lean drilling	30-50%	Womack et al., 1990
Well planning cycle time from a good concept to spud	Lean drilling	40-50%	Womack et al., 1990
Manufacturing			
Lead time reduced	Lean Manufacturing	90%	Kilpatrick 2003; Bhim Singh et al. 2010; Ugarte et al., 2016
Productivity increased	Lean Manufacturing	50%	Kilpatrick, 2003; Amelia N, 2013; Matthias Holweg, 2007; Bhim Singh et al., 2010
Work in process inventory reduced	Lean Manufacturing	80%	Kilpatrick, 2003; Bhim Singh et al., 2010
Quality improved	Lean Manufacturing	80%	Kilpatrick, 2003, Gustavo M et al 2016, Matthias Holweg 2007
Space utilization reduced	Lean Manufacturing	75%	Kilpatrick 2003; S Alex et al., 2010

4.3.4 Lean HSE

The HSE management system is a tool to control and improve health, safety, and environmental performance in all development programs of industrial and other structural organizations. This is an integrated system, so all human, financial, and equipment resources will support each other to provide a healthy and convenient environment with no accidents and injuries (Farshad et al., 2006).

The oil and gas offshore activity is one of the high-risk industries. Thus, the sector gives high emphasis on continual improvement in HSE performance. Developing an HSE culture is a collaborative endeavor that requires the involvement of all concerned players (Buell, 2006).

The two core pillars of lean philosophy are respect for people and continuous improvement. Lean HSE bases its foundation on this philosophy, where HSE performance cultures are promoted by workforce engagement and involvement instead of the traditional approach of HSE compliance and Top-down policy procedures without the front-line employees' involvement.

Mario Cuin (2016) listed various factors that could contribute to an injury-free working environment and factors (processes, tools, and best practices) that promote excellence in HSE practices:

- Setting zero-incident
- Establish HSE Dashboard
- Value stream ownership, accountability, and authority
- Work permit
- Regular HSE training
- Weekly safety meetings
- Frontline engagement, respect for people, workforces involvement
- Job Safety Analysis (JSA), Toolbox talk
- Time out for safety and open communication

Following an established operational procedures with understanding and applying them correctly will reduce the risk of HSE. However, according to lean thinking, since operations and operational areas become complex, the standards and best practices should be continuously updated, and employees must be trained regularly. It is also important to insure that the identified risks are understood to take a correct measures.

Correct radio communication is vital during operation, reducing the risk of misunderstanding and making the job more understandable and effective.

All these rely on the efficient training program, which is essential for personnel on identified equipment and operations and operational limitations due to wind, rig heave, etc. Moreover, follow operational requirements to prevent falling objects from securing tools and materials to prevent them from falling on people below. The use of barricades in hazard areas and post warning signs, use of toe boards, screens on guardrails, or scaffolds help to prevent falling objects.

HSE culture development is not a one-moment endeavor. It needs continuous learning, problem-solving, and experimentation using the scientific problem-solving method, such as PDCA A3, root cause analysis, 5 why, 5S, error proofing, Gemba walk, etc.

4.3.5 Lean Operational safety

Lean thinking is not all about applying lean tools, which some lean practicing companies customary. Lean thinking is a cultural mindset whereby organizations pursue continuous improvement by combining the human side of lean and respect for people. Lean thinking is an all-rounded philosophy that focuses on waste elimination, customer value innovation, smooth process flow, employee engagement and involvement, problem-solving, knowledge sharing, open communication, and continuous collaboration among all stakeholders and players. Some of the lean tools that could promote working environment safety, employees' ergonomics, and value stream visibility are:

- ✓ Five S's (sort; set in order; shine; standardize, and sustain). Using this lean tool, the organization could maintain a visible working environment along the workflow. People could easily see problems, unsafe process lines, and defects before it could result in hazardous situations that may lead to incidents, near misses, and accidents. Emphasis has also been laid on using 5S as a workplace organization method, maximizing efficiency and effectiveness by identifying and storing the items used, maintaining the area and items, and sustaining the new order. In a clean and tidy work environment, it would be easy to see problems exposed to the surface.

- ✓ Error proofing, ‘Poka Yoke’ in Japanese, is a lean tool that helps prevent human error by disabling a system not to function in case of operator error or failure to ‘fail-safe.’ This is one of the practical tools that could be implemented in a process line to stop a process when it is deemed unsafe. For example, a washing machine could not start when the door opened (Shigeo Shingo). Error-Proofing (Poka-yoke) Poka-yoke is a Japanese word for error-proofing (or fail-safe) which involves all the measures taken to minimize or prevent defects from occurring on-site (Conner, 2001).

It is a way of avoiding unintended errors that is simple and cost-effective. It also involves all the necessary actions that prevent hazards from occurring and measures taken to prevent the employee from getting in contact with them. The concept relies on creating ideas that alert the occurrence of potential defects. According to Shingo, a defect occurs when a mistake reaches a customer, and the aim of applying this tool is to prevent those mistakes from becoming defects, Bicheno, (2000).

In Lean manufacturing, Shingo introduced Poka-yoke (fail-safe) devices to prevent defective parts from flowing through the production process with the concept relying on the creation of ideas that alert the occurrence of potential defects (Salem et al., 2005). The use of error-proofing (or fail-safe) devices is key to maintaining improvements in an organization (Pasquire & Connolly, 2002; Bashir, A. M. 2013).

- ✓ “Plan, do, check, act” (PDCA): a continuous process of business improvement method where processes are iteratively done to identify problems and take countermeasures and measure the performance and keep the cycle continuously for continuous improvement (Deming, 1986).
 - ✓ Five whys is an iterative problem-solving method that one uses to ask why until reaching out to discover the root cause of the problem. This has an important implication in working environment safety where it helps to fix the root cause of the problem that could be a source of the accident. When analyzing a problem, there are two root causes to be identified a) Why the defect was made and b) Why the defect was not detected (at the point of cause). The 5Why process, but more importantly, the ‘thinking way’ is a practical yet simple and flexible method to deliver robust results and help ensure that you resolve problems quickly and effectively.

The 5 Whys, the five-time repetition of “why” (5 whys) when confronted with a problem, helps to discover the root cause of the (Nicholas, 1998).

The Toyota production system is developed on the practice and evolution of this scientific approach. The name originated from the fact that “why” needs to be asked at least five times to trace the root cause of a problem Bicheno, (2000). The tool requires the workforce and the management to ask “why?” over and over when a problem occurs. By doing this, the initial cause of the problem could be traced until all defects are exposed and addressed to prevent reoccurrence (Bashir, A. M. 2013).

- ✓ Production leveling, Japanese Heijunka, is a process of leveling production to reduce Mura(unevenness) in production that could result in Muri (overburden) that could wear away machines, equipment, and even workforces that operate the system (TPS, 2001).

The above-mentioned lean tools are just a few examples that could be applied in promoting a working environment safety culture. It is imperative to note that any tool, techniques, and best practices bring fruit whenever it gets buy-in from the workforce and employees' full engagement.

4.3.6 Lean thinking for the long-term integrity

The offshore oil and gas installations need a high level of integrity as these installations are deemed to endure harsh offshore weather conditions and physical contact with seawater. Thus periodic maintenance and inspection are required to keep and integrity of these installation to avoid accidents to people, negative impact on the ecosystem, and damage to assets.

An example of an offshore installation integrity issue was the Piper Alfa incidents in the NCS. Piper Alpha, Offshore, (1988) accident killed 167 workers in the North Sea after a major explosion and fire on an offshore platform. The official inquiry found a number of technical and organizational failures. Maintenance errors that eventually led to the leak resulted from inexperience, poor maintenance procedures and poor learning by the organizations, and the permit-to-work system at shift changeover and safety procedures were not practiced sufficiently (Pate-Cornell, 1993; Cullen, 1990).

The root cause of the Piper Alpha incident indicated that the maintenance error finally led to the leak due to inexperience on the part of operators, poor maintenance

procedures, poor learning by the organizations, and the permit-to-work system. Shift changeover and safety procedures were not practiced sufficiently. These issues should be continuously upgraded; people should be trained and ensure the procedures are implemented correctly and regularly. People organization in the right place and proper data transfer and documentation will minimize the incidence of HSE and structural failure.

Report from Trends in risk level in the petroleum activity (RNNP) indicated that the upstream sector experiences major and minor incidents every year. Continuous and Proper communication between operator/company personnel offshore, onshore, and at a logistic base for efficient mobilizing and de-mobilizing of equipment will impact the operation's effectiveness and reduction of process wastes and inefficiencies. Since the petroleum safety authority is responsible for the safety issues, a regular discussion forum with the operators and other stakeholders will help to update the standards.

It is practiced in the lean community using the methodology Toyota Kata, where processes of learning and experimentation are taken to explore a new target and challenges. It is a continuous learning and problem-solving methodology with a streamlined organization vision shared by all employees.

In line with this, oil and gas companies use After-action review (AAR), a structured review or de-brief (debriefing) process for analyzing what happened? Why does it happen? Moreover, how can the participants and those responsible for the project or event do it better? Similarly, the AAR is the process of analyzing what was planned? What happened? What do we learn? In addition, what can we do better next time? After reviewing these, **PDCA** will follow, and the process will be continuously implemented along with the continuously improved workflows and recommended standards.

4.3.7 Injuries in oil and gas

Safety is a critical issue in the oil and gas industry. The oil and gas industries use a significant number of standards and guidelines. Using these standards enhances technical integrity, improves safety, reduces environmental damage, and promotes business efficiencies that result in reduced costs.

It is common practice to perform a risk assessment for all well operations. When performing the risk assessment for a given operation, such as system installation/construction procedures, it is important to identify any risks associated with

the system that have safety and environmental impact, Bellarby, (2009). Once the risks are identified, they are grouped according to their impacts and the likelihood (probability) (Inderberg & Neuenkirchen, 2010).

The oil and gas industry are currently moving to the digitization and automating operations. A carefully designed workflow would contribute greatly to efficient and optimized operations. For this, an appropriate experience and expertise are the key to interpreting if incase an incident alarm is detected. This will greatly help in moving ahead or conducting a quick remedial action.

The common assert by lean practitioners is that the leading cause of process waste is broken processes. Thus, process waste elimination and employee involvement in continuous process improvement would positively improve the working environment safety culture. When it comes to safety, the authors found it exemplery to refer to the experience of the leading oil and gas operator on the Norwegian continental shelf (NCS). Equinor's Safety standard under the umbrella of 'I am safety' is a personal engagement, and responsibility for safety is the foundation for Equinor's safety culture.

From Northsea offshore day-to-day activities, hand injury is the most common personal incident and accident. Bone fractures were the most frequent reportable accident, followed by strains and lacerations, Fig 4.8 (oil and gas UK).

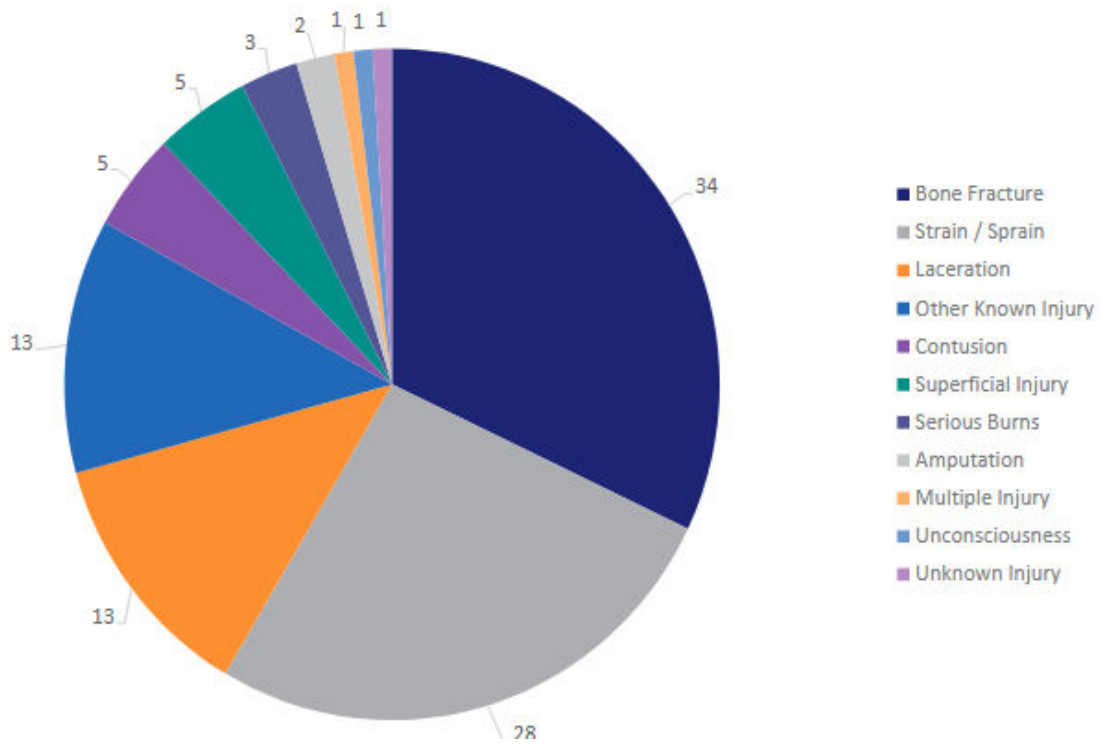


Figure 4.8 Reportable injuries by type (Health and safety, OGUK 2019)

Based on the reports, literature review, and primary data, the author of this study has developed a conceptual model focusing on one of the most frequent injuries, hand injury (Fig. 4.9). The abbreviation HAND has been used as a metaphor to aware each and every employee to focus on the task at hand with high attention. HAND stands for; **H**= Hazard, **A**=Awareness, **N**= Neutralization, **D**= Deliberation/Decision. Thus this is a continuous cycle of focusing on a task by following steps; Hazard assessment and awareness of the danger and neutralizing it, and doing the task with deliberation or safe decision to execute the task at hand. Thus with this simple rule, one would evaluate the potential hazards to safeguard the precious body part hand before we extend our hand to the hazards and dangers around us.

The literature gap identifies that near-misses and minor injuries are usually overlooked, escaped, and left unreported. Nevertheless, whatever small the near misses or injury level, open communication and learning from the incident and improving the process towards value addition to contributing positively to employee safety need to be part of

the organization's culture as safety is a paradigm shift in organizational culture than a one-time program.

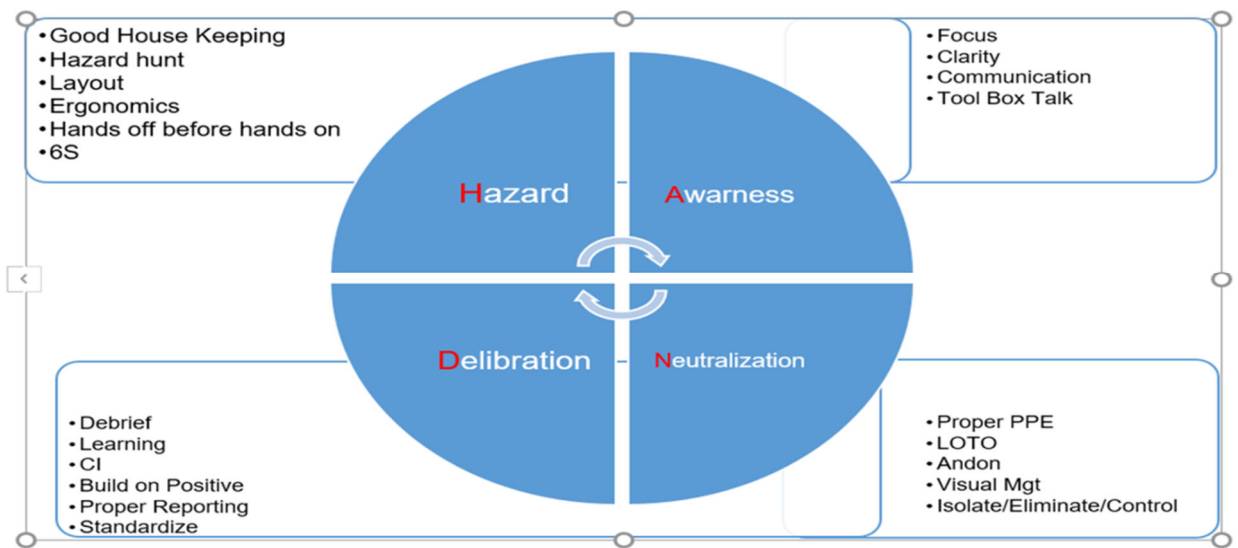


Figure 4.9 Conceptual model for HAND injury awareness (Authors perspective)

4.4 Work environment safety from the context of offshore oil and gas drilling & Production

The contemporary corporate organization's sustainability expressed in terms of social, economic, environmental, and safety aspects are becoming the norm. The globalized business environment has allowed businesses to equally access technology, information, and other important resources. Thus, the differentiating factor in competition is how each of these firms uses their workforce's talent and creativity, gets them involved and engages strategically. Businesses focus on customers' values and continuously innovate business processes.

By its very nature, offshore oil and gas exploration and production activities have a high impact on the environment, social, workforce, and ecosystem, and the consequence of accidents on an organization in particular. Thus, developing an accident-free working environment is in an organization's best interest to pursue business sustainably and acquire the consent of the interest groups (government regulatory body, environmental group, local community, workers union, other industries such as fishing, etc.)

Work environment safety in the context of offshore oil and gas drilling and production is a result of workforce safety culture, offshore installations integrity, company HSE best practices, regulatory body standards, safety management systems, organizational

problem-solving culture, employee engagement and involvement, and continuous HSE improvement culture, a collaboration of all players along the value chain.

Commanding and controlling safety measures as if it was against the employees' interests sends a wrong message as if safety measures are not in line with employees' interests. Safety measures must value the employees' well-being and be leveraged as a common interest to build trust between employees and top management.

Focusing on major accidents and giving less emphasis on near-misses and minor incidents, and not reporting and recording such incidents and communicating company-wide to learn from them led to missing the root causes of accidents and missing how events develop to cause a major accident.

The safety system is part of the overall organization system embedded in every process. One of the common mistakes in safety management is attempting to tackle safety as a one-time endeavor and flavor of the month on a non-continuous campaign approach basis. Contrary to this, lean thinking considers the system approach and tackling problems along the value chain using a value stream mapping approach to identify activities in the process that do not add value; safety is not different. The lean approach advocates people are not the cause of problems. Instead, the broken process is the cause of the problem, not different from safety as a process.

Safety system problem-solving methods need to be bottom-up and up-down. Using Safety staff and frontline employees alone without top management involvement does not bear the envisioned fruit. Safety is everybody's responsibility. The lean approach bases any improvement on respect for people's philosophy. Thus, the employee is the one doing the job and at the same time improving the work process, including safety as part of the process.

Compliance is the foundation and the minimum requirement in safety management. Hence, compliance is not quite enough to prevent accidents and incidents. People-based approaches and continuous safety improvement are beyond regulatory control, where employees go beyond compliance to exert discretionary efforts.

Thus, this study suggests that the lean philosophy of employees' engagement, workforce involvement, cross-functional collaboration, and committed leadership complements the safety system of standards, procedures, policies, and regulations. Lean is a people system; people are the key to breaking or realizing a safety system in the

work environment to keep themselves and others safe. Hence, a lean thinking-based safety system is a people-based safety system that would allow the individual employee to focus on the task with the right to stop the work in case of doubt, unsafe acts, and unsafe conditions.

The overall results of effective lean thinking implementation are improved productivity, minimized cost, reduced non-productive time, and reduced waiting related to incidents and accidents. The author of this study argues that there is a missing factor in the equation of offshore oil and gas activities by not giving the weight it needs to involve and engage the frontline employees in devising a continuous improvement system. The human side of the equation has been given less weight and emphasis to standards, procedures, regulations, and policies. As is customary in lean thinking practices, the key secrets of an outstanding organization could be the foundation of the organization on one of the two pillars: respect for employees.

4.5 Accident causation theory

It is imperative to know accident causation reasons to apply mitigating and controlling measures accordingly. Among the many theories of accident causation theories, this research focuses on the Domino accident causation theory and ‘Swiss Cheese’ accident causation theory, as these two are the most used theories in the oil and gas industry. Pejman et al. (2013) argue that most workplace accidents originate from human errors and operation sources such as equipment and assets in work processes settings.

In oil and gas, most incidents cause minor injuries and near-miss incidents. The leading causes for these incidents are attributed to unsafe acts; other possible causes are unsafe conditions. To identify the reasons or the factors contributing to accidents, several theories have been developed by researchers. Domino theory is one of the dominant ones.

Accidents within oil and gas sites usually come from heights, machines, being struck by falling objects, and vehicle crashes, Wang, W., Liu, J., & Chou, S., (2006). Some accidents cause the conditions to lead to downtime and expenses due to remedy and compensation. Domino theory focuses on developing a coherent theory that can define and justify the accident factors. It also emphasizes the processes contributing to accidents occurring within the workplace at all levels of employees, from general workers to engineers and managers.

Herbert William Heinrich developed a theory called Domino theory (1929). The theory has been developed many times during several years. The steps of accident causations labeled on five metaphorical dominos in the sequences are shown below, Fig 4.10:

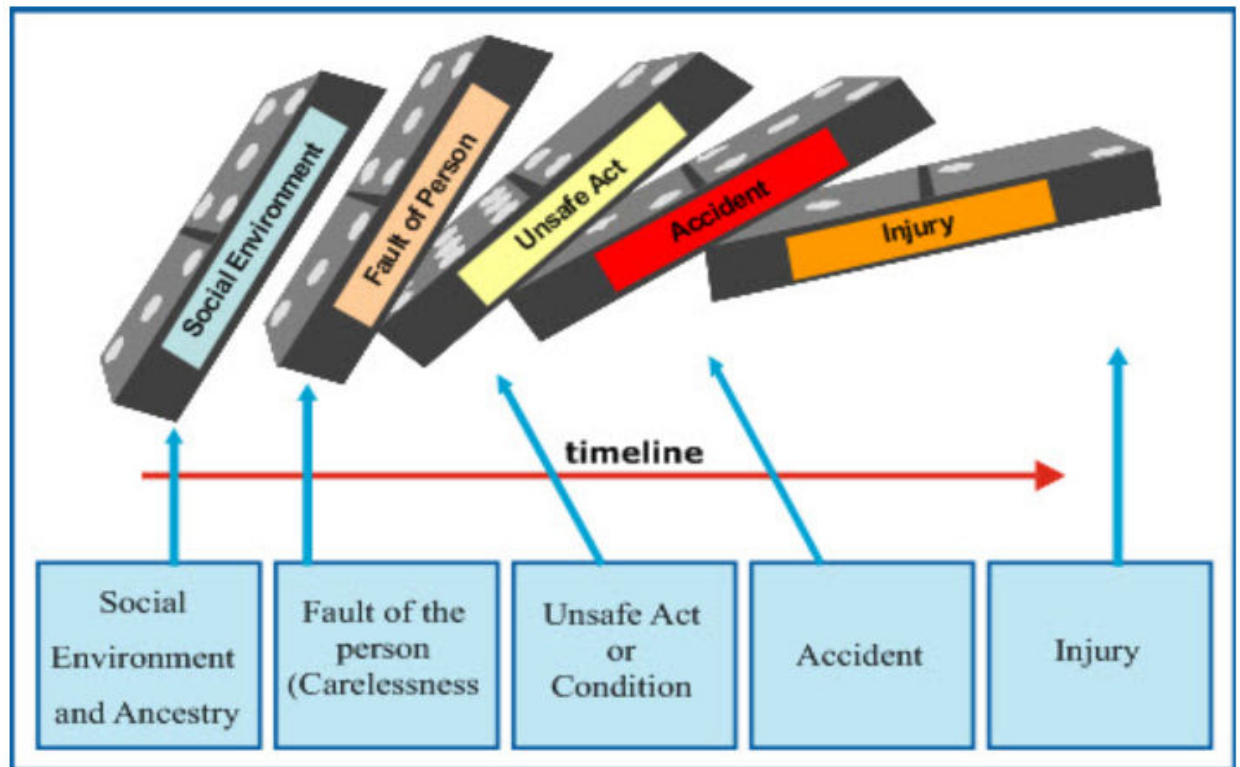


Figure 4.10 Heinrich's Domino's sequences of accident causation theory, (Rad, K. G. (2013)

- Social Environment and Ancestry: Some characteristics such as recklessness, greed, and bad temper are originated from either inheritance or social environment. In other words, such traits can be raised by nature and nurture, contributing to a person's fault.
- The Person's fault: Some unpleasant manners or traits such as ignorance, recklessness, and bad temper can be innate. Also, such traits can appear due to life environments contributing to unsafe Acts or conditions.
- Unsafe Acts or Conditions: Unsafe acts and unsafe conditions are labeled on the domino at the center of sequences contributing to an accident. They are the most significant factor to cause an accident (Michalis & Myrto, 2012).

Fig 4.11 illustrates the most common contributing factors to the occurrences of

the accident: unsafe equipment, job site condition, unique nature of the industry, unsafe method, human element, management, etc.

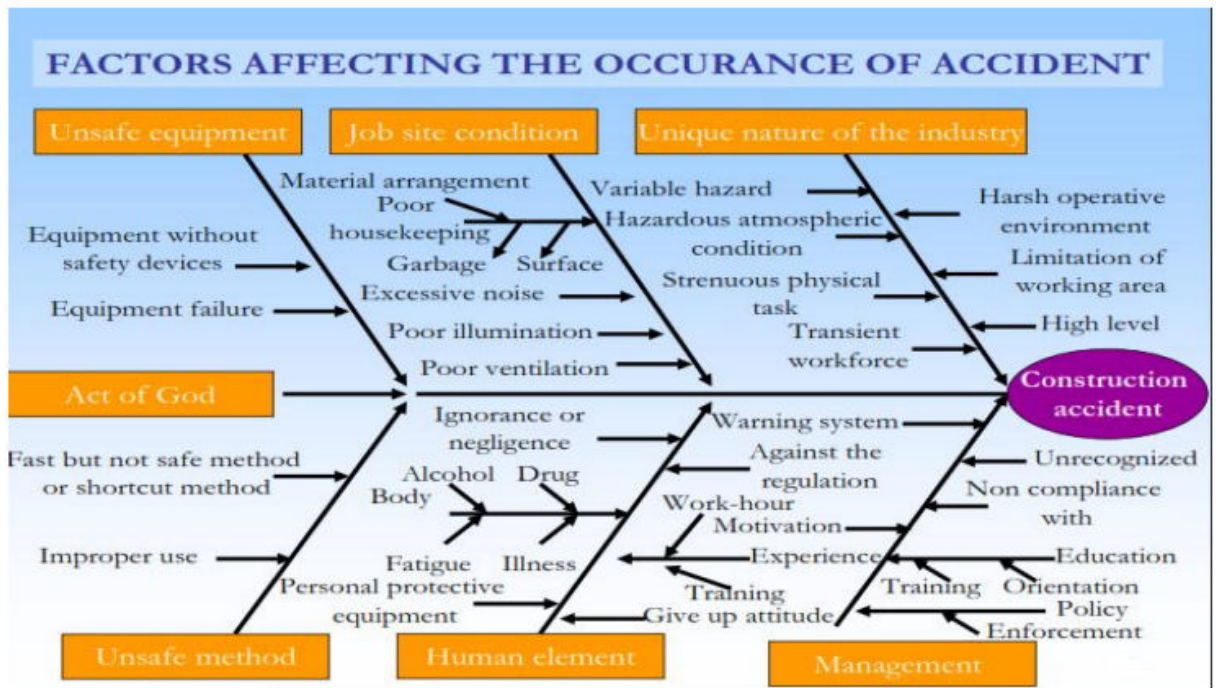


Figure 4.11 Workplace projects Features, Michalis & Myrto, (2012).

Accidents at workplace sites are unplanned occurrences involving the movement of persons, objects, or materials which may result in injuries, damages, and losses to properties or people. Most accidents happen as a result of unsafe acts and unsafe conditions. Causation theories are in recognizing how hazards in the workplace workplaces cause losses (Seyyed & Zahra, 2012).

4.6 Workplace injuries in the oil and Gas context

The oil and gas industry will be the primary energy source for the future. The oil and gas exploration and production processes are considered the most hazardous activities. The sector sustains various kinds of injuries, from minor to major ones. Among the minor injuries, hand injury is the most frequent in the workplace daily. The good news is these injuries could easily be prevented with continuous safety system improvement and active participation, engagement, and workforce involvement.

Oil and gas safety practices should be more than compliance with the regulation. Compliance is important, but compliance alone could not spare the industry from incidents and accidents. Safety should be considered a competitive advantage that could

give the sector a competitive edge to do the sector's business competitively and safely. Mindful safety practices are the ability to be aware of the environment's critical factors and act appropriately when dangers arise (Øyvind & Trond, 2018).

The oil and gas safety practice and agenda should incorporate every employee on the same page and have a shared vision of safety as an essential value in the value chain that every player in the sector needs to be shouldered. To this end, coordination among the players is imperative (Jan Hovden et al., 2008).

The very nature of the products the sector produces and the remoteness of the working environment exposed the sector to a more hazardous environment than other industries. The fast growth in the industry globally has raised concerns about safety and health issues in the workplace. As a result, more occupational accidents and injuries in the workplace make headline news all over the globe (Wameedh et al., 2011).

The upstream oil & gas industry has been frustrated by the sector's stubbornly high rate of injuries and fatalities. As the saying goes, Management guru Peter Drucker once said, "Only what gets measured, gets managed." As this quote exemplifies, it could apply to safety data. Fortunately, the oil and gas industry has access to huge safety data that could help measure and manage the industry's safety performance. The industry may make considerable progress by applying "Big Data" analytical tools to the large volumes of safety-related data collected by these organizations (Kim Hua et al., 2016). In the current oil and gas business conditions, profit margins are diminished, which could lead to productivity compromising safety measures. Interest in developing an appropriate safety culture in the oil and gas industry has taken center stage among stakeholders. Human behavior has been identified as a major contributor to occupational accidents, where abnormal activities associated with safety management are considered normal behavior. Lack of good safety culture is one of the major factors influencing employees' safety behavior at work, which may result in injuries and accidents. Promoting such a culture can improve workers' safety performance (Ehiaguina & Moda 2020).

Oil and gas are one of the conservative industries with capital-intensive investment and many different players operating in parallel at a particular project, sometimes with less visual collaboration and clear communication in the value chain, especially across the suppliers' line. The oil and gas industry boasts a hard-earned reputation of being able to get the job done anytime, anywhere. Unfortunately, this distinction has also produced an inherent attitude that too often puts the job first, regardless of personal safety. The

industry began promoting a "safety first" approach to confront the ongoing stigma of poor safety practices. As admirable as this goal is, many health, safety, and environmental (HSE) professionals found that deeply ingrained attitudes and practices are challenging to change (Ratliff, 2004).

The author of this research argues that the oil and gas industry has to do more to innovate its safety system so that injury rates could be reduced and incidents and accidents would be minimized as low as reasonably practicable. There is increasing interest in risk and safety research to reflect risk fluctuations in the operational phase to avoid major accidents (Xue Yang et al., 2018).

During the last few years, there is an increase in occupational accident figures in different workplaces around the world. A number of causes contribute to these accidents, but one of the main causes is human error. In the context of the Oil and Gas (O&G) industry, human error constitutes the largest contributor to all accidents. As the O&G industry has the most hazardous working environment and deals with various hazardous chemicals and operations, the consequence of these accidents is too high for the employees, workplace, economy, and society (Alkhaldi et al., 2017).

Oil and gas field projects are performed with job safety analysis, focusing on risk identification for risky tasks. A Permit to Work is an integrated part of an Oil and Gas company's Safety Management System and a key component of a Safe Work System. A PTW System helps to certify that all work is planned, communicated, controlled, and carried out safely. Permit-To-Work is a proven best-practice method to confirm safety practices on dangerous hazardous worksites. A permit is a written, signed legal document distributed to all concerned bodies involved in the task at hand and is a means of communication between site management, plant supervisors, operators, and those who carry out the work (Rizwan & Al-Marri 2012).

Before incidents surfaced and were visible at a workplace, Fig 4.12, they would stay hidden below in the forms of an unsafe condition and unsafe act. That is why oil and gas companies must practice hazard hunts in the work processes.

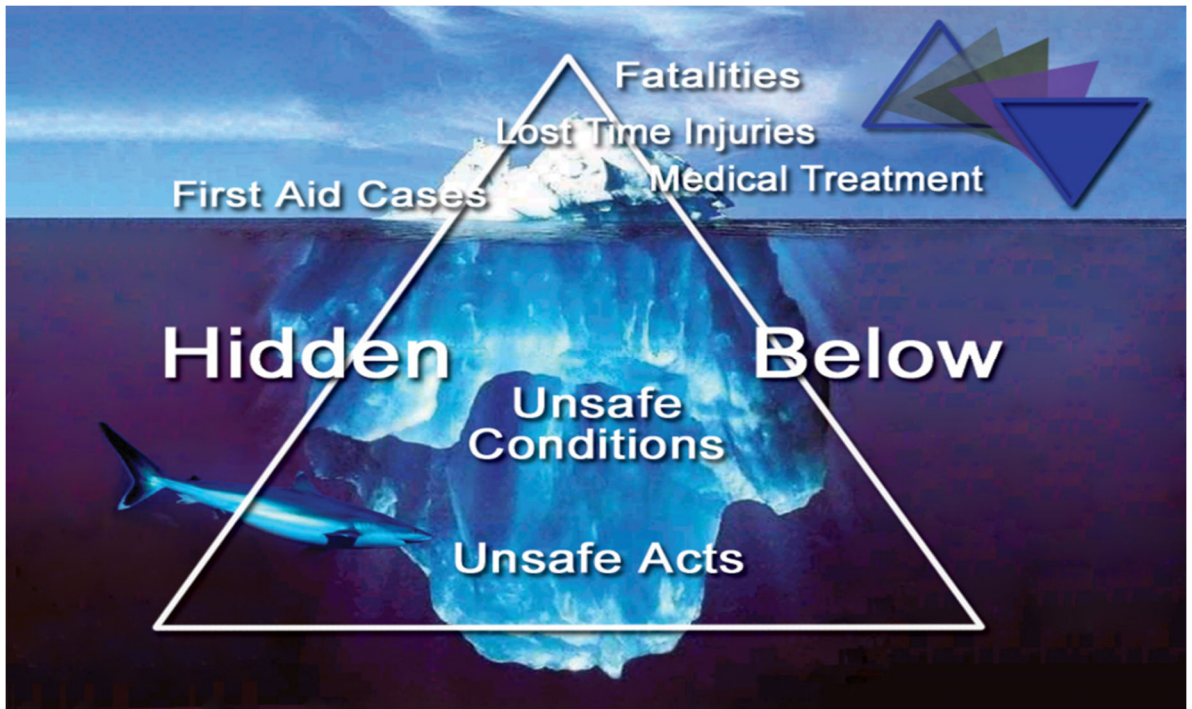


Figure 4.12 Iceberg example unsafe act and conditions, Source: Total Safety Culture Presented by Jason Thompson Total (slidetodoc.com)

4.7 Primary and secondary data presentation

Hand injury is one of the most frequent injuries in the oil and gas industry. One-third of all oil and gas industry accidents are hand injuries. The industry uses various campaigns to avoid hand injury and applies engineering and work practice controls to protect employees from potential hand injuries.

Potential Hand Hazards include:

- Skin absorption
- Severe cuts, lacerations, or abrasions
- Fractures and amputations
- Punctures
- Chemical or thermal burns
- Electrical dangers
- Harmful temperature extremes, Source (OPEC safety, PPT-SM.HANDSFTY 2014).

Parkes & Swash (1999) argue that the upper extremities were the most frequently injured body part, and crush injuries were mainly associated with drilling activities.

Moreover, the authors found that the most common incident types were slips/trips/falls, handling goods and materials, use of machinery, and lifting/crane operations; however, these different types of incidents were significantly distributed across work areas. In the offshore oil and gas industry, especially when there is pressure on project completion, longer working hours, extreme weather conditions, and some work areas (e.g., drilling) are identified as disproportionately hazardous (Parkes & Swash, 1999).

The oil and gas industry's upstream safety system has developed through time. The sector has been transforming the safety systems, plans, procedures, and work instructions. The sector players, operators, engineering service companies, drilling contractors, and other third-party contractors are combining efforts to create a safe working environment. Unfortunately, the sector is still engaging in minor to major accidents and injuries that cost a tremendous amount of money and affect the productive workforce of the sector.

The new unconventional oil and gas exploration and production technologies, such as multilateral drilling and Hydraulic fracturing, have opened the way for exploring oil and gas resources in uncharted areas and remote locations, which were previously deemed uneconomical with conventional drilling techniques Witter et al.,(2014). This development has posed extra safety hazards to the working environment. The oil and gas workplace fatality frequency is 2.5 times greater than the construction industry and seven times higher than the general industry; however, injury rates are lower than in the construction industry (Witter et al., 2014).

Safety hazards are all around us. It is not easy to avoid and eliminate all hazards, but we can create an injury-free workplace. Workplace injuries are an unwanted output within the upstream oil and gas activities. Li-Ting Yeh (2017) argues a number of studies on workplace injuries have used various econometric models to examine the elements that affect safety performance. An efficient safety policy is required to reduce workplace injury that engages and involves the frontline employees.

Since 1968 the oil and gas industry has been the backbone of Norway's economy. With stringent safety regulations from the Norway Safety Authority and oil and gas industry-wide safety system reform, the industry is doing its best to control operational hazards. Daniel et al. (2017) assert that it is important to monitor the operational hazards by

using applicable safety indicators for proactive prevention of accidents in the upstream oil and gas sector.

HSE management is a vital ingredient of Oil and Gas industry operations because most of the operational conditions, chemicals, and end products (hydrocarbons and other compounds) associated with Oil and Gas production are well-known to pose serious safety and health threats to the employees.

Considering the hazardous nature of the Oil and Gas industry, implementing an efficient occupational HSE Management System is crucial for improving HSE performance. On 10th June 2013, the EU developed a Directive on safety for offshore oil and gas operations. Due to regulatory compliance pressure, the principal responsibility of ensuring operational safety and sustainability is placed on the Oil and Gas industry (Neha Chauhan, 2013).

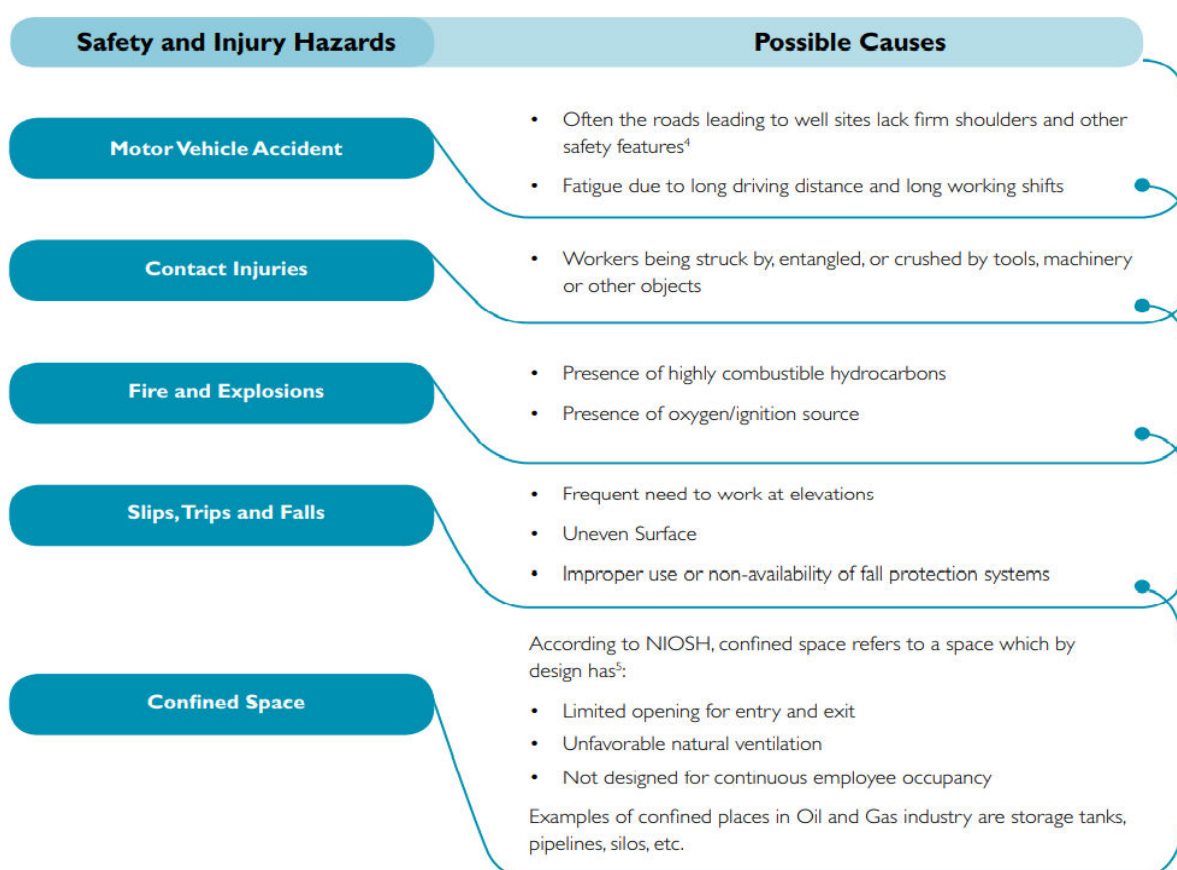


Figure 4.13 Safety and injury hazards in oil and gas

Accident prevention is the key to any organization's effective Health, Safety, and Environmental management system. Hazards are different for different industries;

subsequent safety risks are not uniform. A need arose to review and interpret the accident patterns (Siva & Nihal, 2015).

In the 21st century, organizations have realized that workplace injuries are no longer tolerable. Nevertheless, the focus was on reacting to accidents and their corrective actions. A need has arisen to understand the root causes of accidents, learn lessons from past incidents, and establish a sustainable safety culture.

Job safety Analysis focuses on the relationship between the worker, the task, the tools, and the work environment. As the phrase, 'job safety analysis is not restricted to only the identification of hazards, but the implementation of controls (Mitigation plans) and validation and the usefulness of those controls, the word 'safety' will have a more focused meaning in the context of the assessment of risk in a job. A JSA is a task-oriented risk assessment that a work team can apply before undertaking a potentially hazardous activity (Rizwan & Al Marri, 2012).

Employers also have indirect costs related to incidents, and these include Loss of soft and hard skills and expertise of the employee; Costs related to getting a new employee to replace the injured employee, including overhead costs, training, medical reviews, etc.; Repatriation costs associated with returning the worker to their home (port Mills, 2009; Martinovich, T. 2013).

Working in the offshore industry is demanding of various factors, some of which are:

- Working away from family for extended periods;
- Withdrawal from society for extended periods;
- Working on sea
- Working on a confined platform
- Lack of social outlet or interaction;
- Physical nature of the work;
- Extended hours of work;
- The need for continuous support from land connectivity;

(Pryor, 2009)

While shift work is important to the economy, evidence suggests that it is associated with a physical and emotional toll on employees (Yueng-Hsiang, Jiu-Chiuan, DeArmondc, Cigularovc, & Chenc, 2007).

Work-related accidents are unacceptable in terms of human, environmental and commercial costs. In order to eliminate work-related injury and illness, it is imperative to develop a set of concepts that are equally applicable to all events and lead to improved accident/illness prevention strategies, Reason (1997).

Quite a good number of global employees are employed directly or indirectly by the O&G industry. As a result of the nature and location of oil and gas operations, the risks of incidents happening in this particular industry are higher than in most other industries. According to the US national safety council, non-fatal work-related injuries are 49% higher in the O&G field services industry than for all US industries combined, and these injuries are more severe. This is a disturbing statistic, particularly since most companies in this domain consider occupational safety a high priority. However, serious injuries still challenge the industry's development (Hackitt, 2010).

Most injuries in the offshore O&G environment are due to minor incidents related to slips, trips, falls, or manual handling. Improper ergonomics in the working environment or layout design can also contribute to these injuries through fatigue, human error, and high workloads (Hackitt, 2010).

Mearns, Flin, Gordon, & Fleming (2001) argue that 'unsafe' behavior is the 'best' indicator of accidents and near misses. The high frequency of work-related injuries affecting young workers and people new to the industry could be attributed to a number of factors, including lack of information, lack of training, lack of supervision, lack of experience on the job, and lack of knowledge and skills. It is important to note that many workers in this industry begin work early, often without adequate safety training (Knox, 2009).

Firms need to understand that as the workforce continues to age, diversify and change, they need to adapt and modify how they manage the needs of the employees, Hackitt, (2012). There are 5 main groups of health hazards in the offshore O&G industry:

- Musculoskeletal disorders (manual handling, ergonomics)
- Hazardous substances
- Physical hazards (noise, vibration, asbestos, and radiation)
- Biological hazards (food/water hygiene)
- Psychosocial hazards, stress, anxiety, etc. Hackitt, (2012).

The very nature of the substances handled by oil and gas makes it one of the most hazardous working environments. Thus, extraordinary measures and active involvement by all players is imperative to keep the workplace safe for the employees. The primary data collected from supplier Y Company's field employees have been presented below. Supplier Y company has around 50 employees working on offshore field sites. 50 questionnaires were sent via email, and 34 were collected. Supplier Y is a multinational company with activities all over the world.

Table 4.2 Supplier Y questionnaire respondents' profile

Company	Respondents country of origin	%	Gender		Remarks
			Male %	Female %	
Supplier Y	Norway	43%	93	7	
	UK	3%	100	-	
	Romania	6%	50	50	
	Portugal	3%	100	-	
	Latvia	6%	100	-	
	Somalia	6%	50	50	
	Sudan	3%	100	-	
	Italy	6%	100	-	
	Iran	3%	100	-	
	Poland	12%	100		
	Serbia	3%	100	-	
	Germany	6%		100	
	Subtotal	100%	83%	17%	

Table 4.3 Questionnaire response for the four questions presented

Question	Opinion A Respondents	Opinion B Respondents	Opinion C Respondents	Opinion D Respondents	Remarks
Question1(drafting)	27 %Top	6 % (Safety Off.)	6 %(frontline)	61 % (Regulators)	
Question2(cause)	18.2% (employee)	39.4%(broken)	42.4% (unsafe condition)	0	
Question3 (Injury Type)	88 % (hand)	12 % (back)	0	0	
Question4	0	54.6%	45.4%	0	

Questionnaires result discussion.

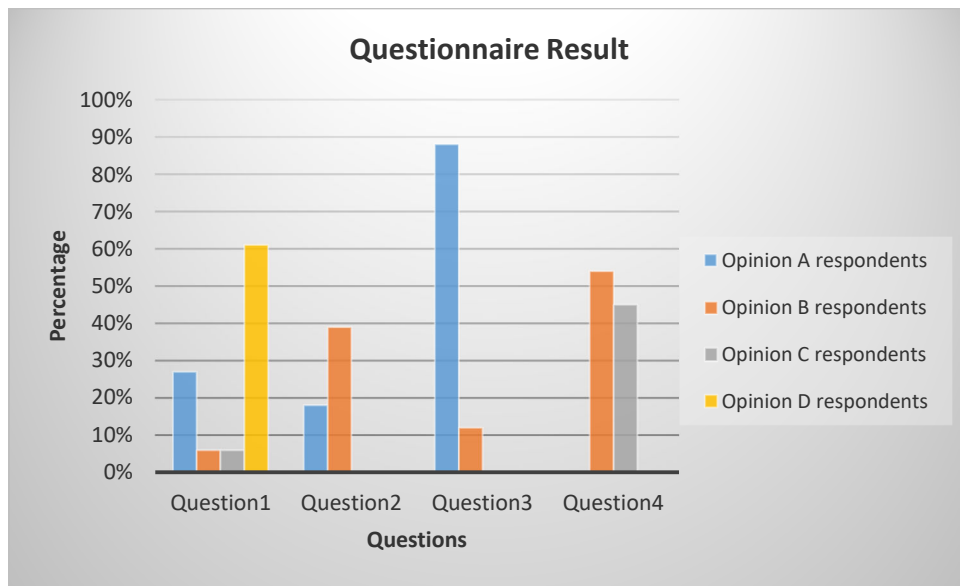


Figure 4.14 Questionnaire Result

Question 1.

In your opinion, who do you assert has the **main** responsibility in drafting oil and gas safety systems, procedures, plans, and policies?

- A. Top management B. safety officer C. frontline employees D. regulatory bodies
- 27% of the respondents assert top management, 6% of safety officers, 6% of frontline employees, and 61% regulatory bodies are responsible for drafting oil and gas safety system procedures, plans, and policies. This is the best indicator that the oil and gas safety system is driven by compliance. The author of this study argues that compliance is the basis of the safety system; the industry needs to do beyond compliance to avoid safety incidents. With 100% compliant safety system, we could still encounter safety incidents. Thus the industry needs to engage in a paradigm shift of tackling safety issues with non-conventional methods such as lean safety with continuous safety improvement.

Question 2.

In your opinion, what could be the **main** cause of accidents in the oil and gas upstream offshore sector?

- A. Employees B. broken processes C. unsafe conditions

18.2% of respondents assert employees, 39.4% broken processes, and 42.4 % unsafe conditions are the main cause of oil and gas upstream offshore sector accidents. Research indicates that unsafe act causes 90% of accidents. But most of the safety measures are addressed to minimize unsafe conditions, contributing to accident causation by just 10%.

Question 3.

In your opinion, what is the common injury type in the oil and gas upstream offshore sector?

A. Hand injury B. Back injury C. eye injury D. Neck injury

88% of respondents assert that hand injuries and 12% back injuries are common in the oil and gas upstream offshore sector. This questionnaire result is in line with the findings of secondary data. As the frequency of hand injury is alarmingly high, the author of this study developed a Hand-cycle conceptual model to minimize the frequency of Hand injury.

Question 4.

In your opinion, what is the leading indicator for predictive safety measures for the oil and gas upstream offshore sector?

A. fatality B. recordable injuries C. near misses D. lost-time days

54.6 % of respondents assert that recordable injuries and 45.4% near misses are the leading indicators for oil and gas upstream offshore sector predictive safety measures. This result indicates that minor injuries are the most active type compared to fatality. Still, surprisingly, top management, media, and the industry focus on fatality and take the minor injuries untouched without realizing that fatality results from unnoticed near-misses and minor injuries.

Secondary data has been collected from International Oil and Gas producers to illustrate the safety trends and injury status in the oil and gas work environment, described by cause activity, region, total recordable injury rate, incident, fatalities, function, country, organization type (operator, supplier, contractor, etc.).

<p>Bypassing Safety Controls</p> <p>Obtain authorisation before overriding or disabling safety controls </p> <ul style="list-style-type: none"> • I understand and use safety-critical equipment and procedures which apply to my task • I obtain authorisation before: <ul style="list-style-type: none"> – disabling or overriding safety equipment – deviating from procedures – crossing a barrier 	<p>Confined Space</p> <p>Obtain authorisation before entering a confined space </p> <ul style="list-style-type: none"> • I confirm energy sources are isolated • I confirm the atmosphere has been tested and is monitored • I check and use my breathing apparatus when required • I confirm there is an attendant standing by • I confirm a rescue plan is in place • I obtain authorisation to enter 	<p>Driving</p> <p>Follow safe driving rules </p> <ul style="list-style-type: none"> • I always wear a seatbelt • I do not exceed the speed limit, and reduce my speed for road conditions • I do not use phones or operate devices while driving • I am fit, rested and fully alert while driving • I follow journey management requirements
<p>Energy Isolation</p> <p>Verify isolation and zero energy before work begins </p> <ul style="list-style-type: none"> • I have identified all energy sources • I confirm that hazardous energy sources have been isolated, locked, and tagged • I have checked there is zero energy and tested for residual or stored energy 	<p>Hot Work</p> <p>Control flammables and ignition sources </p> <ul style="list-style-type: none"> • I identify and control ignition sources • Before starting any hot work: <ul style="list-style-type: none"> – I confirm flammable material has been removed or isolated – I obtain authorisation • Before starting hot work in a hazardous area I confirm: <ul style="list-style-type: none"> – a gas test has been completed – gas will be monitored continually 	<p>Line of Fire</p> <p>Keep yourself and others out of the line of fire </p> <ul style="list-style-type: none"> • I position myself to avoid: <ul style="list-style-type: none"> – moving objects – vehicles – pressure releases – dropped objects • I establish and obey barriers and exclusion zones • I take action to secure loose objects and report potential dropped objects
<p>Safe Mechanical Lifting</p> <p>Plan lifting operations and control the area </p> <ul style="list-style-type: none"> • I confirm that the equipment and load have been inspected and are fit for purpose • I only operate equipment that I am qualified to use • I establish and obey barriers and exclusion zones • I never walk under a suspended load 	<p>Work Authorisation</p> <p>Work with a valid permit when required </p> <ul style="list-style-type: none"> • I have confirmed if a permit is required • I am authorised to perform the work • I understand the permit • I have confirmed that hazards are controlled and it is safe to start • I stop and reassess if conditions change 	<p>Working at Height</p> <p>Protect yourself against a fall when working at height </p> <ul style="list-style-type: none"> • I inspect my fall protection equipment before use • I secure tools and work materials to prevent dropped objects • I tie off 100% to approved anchor points while outside a protected area

Figure 4.15 Lifesaving rules, IOGP, 2018

Fig. 4.15 lists the nine lifesaving rules most practiced in oil and gas company safety meetings, safety inductions, and hazards hunt and risk analysis.

Secondary data collected from International oil and gas producers (IOGP) are

tabulated in the tables below to show fatalities in the oil and gas industry by cause, activity, regions, and functions.

As shown in Fig 4.16, Explosion, being caught in between, and being struck by are the three most causes that led to Fatalities (2015-2019)

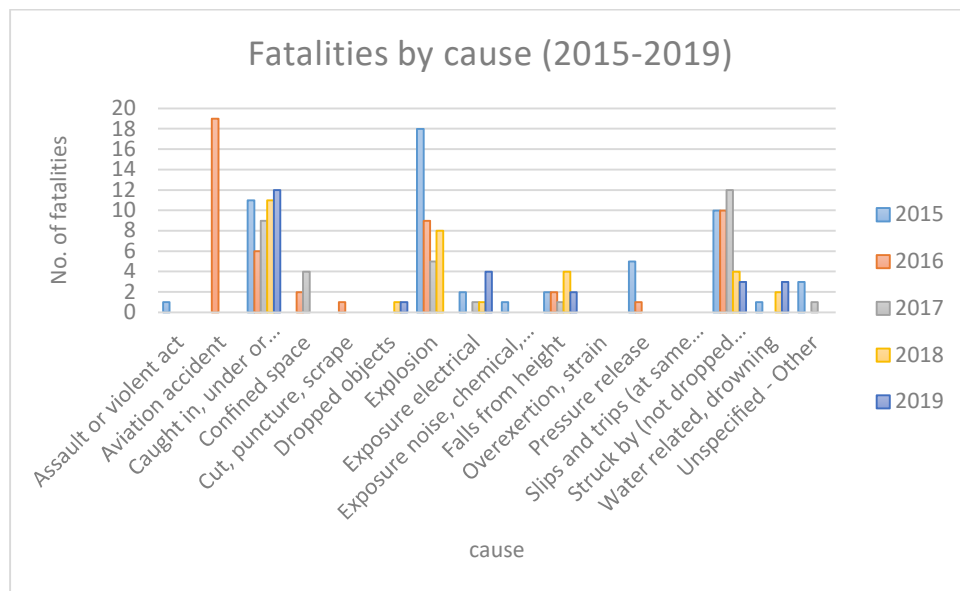


Figure 4.16. Fatalities by cause 2015-2019, IOGP

As illustrated in Fig. 4.17, production, drilling, and transportation are the three main activities that caused the highest fatalities, Fatality by activity (2015-2019)

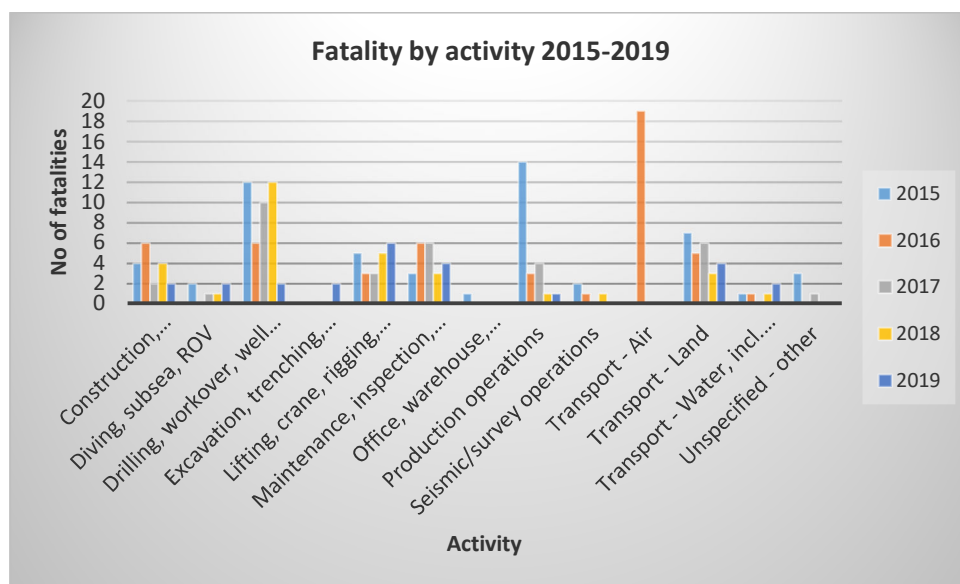


Figure 4.17 Fatality by Activity 2015-2019, IOGP

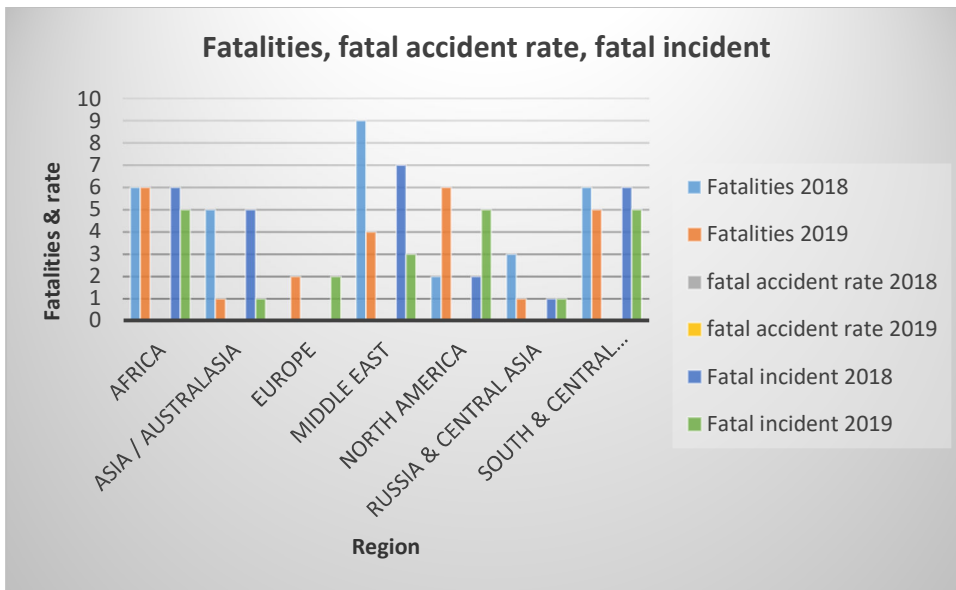


Figure 4.18 Fatalities, fatal accident rate, fatal incident, IOGP

Fig. 4.19 shows that the total recordable injury rate is the highest for the region of Europe in 2019. This is a typical indicator of under-reporting by some regions.

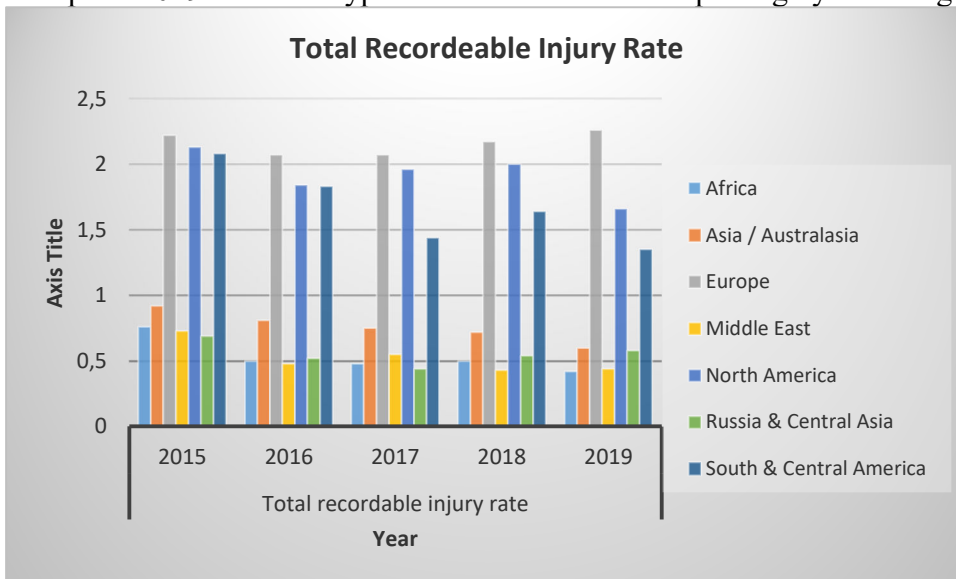


Figure 4.19 Total Recordable Injury rate, IOGP

Fig. 4.20 shows that production and drilling activities recorded the highest fatal incidents and fatalities, and 2015 was the deadliest year.

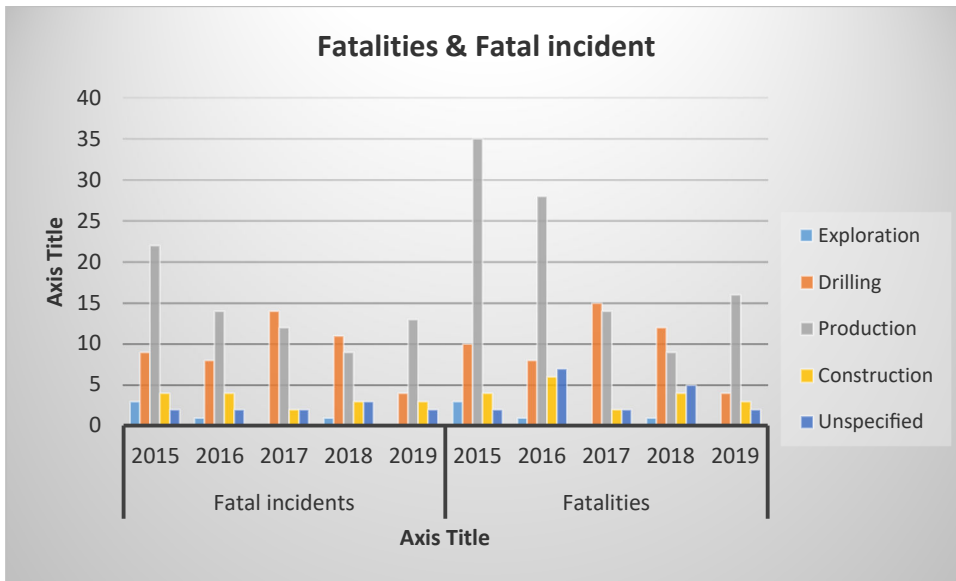


Figure 4.20 Fatalities and fatal incident, IOGP

Fig. 4.21 shows that offshore activities recorded the highest total recordable injury rate, and the contractor employees are the most affected compared to Company (operator) employees.

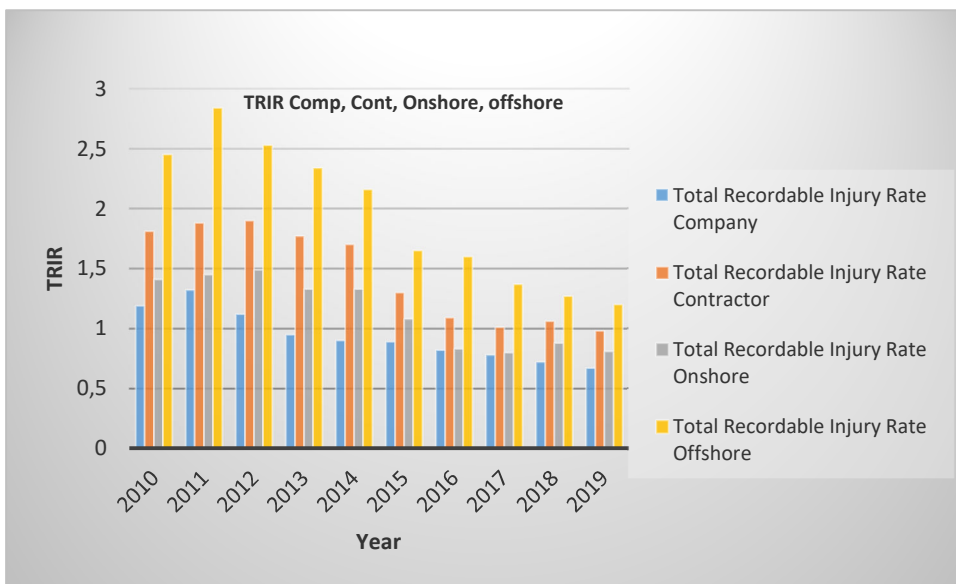


Figure 4.21 TRIR Company, Contractor, onshore, offshore, IOGP

4.8 Chapter Summary

The lean eight wastes are contextualized to pinpoint the wastes in relation to the oil and gas industry safety system. The author of this study also presented the 9th waste proposition using own perspective on, Safety incident as the 9th waste. Lean tools with unique enabling factors for promoting safety were discussed. These lean tools were: 5S, Error Proofing, PDCA, 5Why, and Heijunka (Production leveling).

The author of the study developed a conceptual model focusing on one of the most frequently active injury types in the oil and gas industry. Based on the reports, literature review, and primary data, the author of this study has developed a conceptual model focusing on one of the most frequent injuries, hand injury (Fig. 4.9). The abbreviation HAND has been used as a metaphor to make aware each and every employee to focus on the task at hand with high attention. HAND stands for; **H**= Hazard, **A**=Awareness, **N**= Neutralization, **D**= Deliberation/Decision. Thus this is a continuous cycle of focusing on a task by following steps; Hazard assessment and awareness of the danger and neutralizing it, and doing the task with deliberation or safe decision to execute the task at hand. Thus, with this simple rule, one would evaluate the potential hazards to safeguard the precious body part hand before extending our hand to the hazards and dangers around us.

Primary data were collected from Supplier Y company employees. Questionnaires were sent to 50 field employees of Supplier Y employees, and 33 of them returned. 27% of the respondents assert top management, 6% of safety officers, 6% frontline employees, and 61% of regulatory bodies are responsible for drafting oil and gas safety system procedures, plans, and policies.

18.2% of respondents assert employees, 39.4% broken processes, and 42.4 % unsafe conditions are the main cause of oil and gas upstream offshore sector accidents. 88% of respondents assert that hand injuries and 12% back injuries are common in the oil and gas upstream offshore sector. 54.6 % of respondents assert that recordable injuries and 45.4% near misses are the leading indicators for oil and gas upstream offshore sector predictive safety measures.

The secondary data from International Oil and Gas Producers (IOGP) shows that production and drilling activities recorded the highest fatal incidents and fatalities, and 2015 was the deadliest year (Fig. 4.20). Offshore activities recorded the highest total recordable injury rate. The contractor employees are the most affected compared to Company (operator) employees (Fig. 4.21). The total recordable injury rate is the highest for the region of Europe in 2019 (Fig. 4.19). This is a typical indicator of under-reporting by some regions. As shown in (Fig 416), Explosion, being caught in between, and being struck by are the three most causes that led to Fatalities (2015-2019).

Chapter Five

5. Model Development

5.1 Oil and Gas workplace Injury rate

Workplace injuries are common and destructive to persons, organizations, and society. Various instruments presently exist designed to assess workplace injury factors (Fullarton & Stokes, 2007). For this dissertation, primary data and secondary data were collected. The primary data was collected from Supplier Y company employees with rich experience in the upstream sector of North-sea exploration and drilling. The primary questionnaire was designed based on the research questions and taking advantage of the safety guru approach to safety excellence (Dan Petersen, 2003).

There is considerable variability in occupational injury rates across companies, even within the same industry. In the Operator's company, Operator X, secondary data was used to develop a continuous safety system improvement model. The model has been developed in such a way that it could predict workplace injury rates.

The formula to calculate lost time injury frequency rate per million hours worked, LTIFR.

It is as follows: No. of lost-time injuries in the reporting period, X 1,000,000 divided by total hours worked in the reporting period (McVittie et al., 1997).

The company's LTIFR indicates lost time injuries for every million person-hours worked. LTIFR can benchmark the safety performance of a company, sector, or industry compared to its peers in the industry or across industries.

Oil and gas safety system continuous improvement scheme should be determined for lowering LTIFR. The workplace lost injury rate could be reduced by creating a safety culture involving employees in the safety system. Naturally, the frontline employees are the ones that pay the highest cost and the ones exposed to severe hazards. Thus, the frontline employees are best placed to improve the safety system continuously. This could be achieved by reporting incidents and near misses, suggesting safety improvement ideas, and actively participating in innovating the safety system.

It has been best practice in the oil and gas industry to do toolbox talk, job safety analysis, hazard hunt, work permit, and risk assessment according to the job. Clear and timely

communication among all parties involved is imperative to have everyone on the same page and avoid misunderstanding and confusion at work (McVittie et al., 1997).

The O&G industry has been through a period in which substantial cost reductions have been made in order to match expenditure to income levels. Restructuring in the petroleum industry has sparked a discussion on whether comprehensive cost reductions may increase the risk of undesirable incidents. The Norwegian petroleum safety authority has identified the following key features:

- The involvement of employee representatives in HSE cases arrives too late.
- Insufficient time is allocated to safety work.
- Lack of training/expertise among safety delegates.
- Employee participation becomes weaker as the contract chains lengthen.
- HSE departments taking over aspects of the safety service's role.

5.2 Random Forest Model for system model development

This dissertation uses a random forest prediction model to predict the injury frequency rate of upstream oil and gas accidents. The Random Forest method was first proposed by Leo Breiman and Adele Cutler, 2001. It is a machine learning algorithm that trains and analyzes samples through multiple trees. The decision trees are classification models that predict categories or take labels by inputting features. At the same time, the random forest is a model composed which multiple decision trees due to different training data. Its result combines all decision tree outputs, which is more stable and with higher prediction accuracy.

Random sampling with replacement in the Random forests progresses, and select each tree from the entire set. The relationship of the feature at this node needs to be calculated at each node, and then select one branch to move to the next node according to the operation result.

Random Forest Model is easy to operate than a ready-made random forest bagging (R) in R. In Random forest prediction, the data is divided into two parts, for example, for this study: 80% of the training samples and 20% of the testing samples, (Sun Yuxuan, 2014); Zhou Qian et al., 2006; Zhang Weihua et al., 2009; Wu c.H et al., 2004).

The important evaluation function of the RF injury frequency rate model offers the capability to assist decision-makers in evaluating the oil and gas sector injury rate

related to various activities and total hours worked in a million and a number of reported accidents.

RF is one of the most widely used Machine Learning methods in real production settings. Random Forest is one of the most popular algorithms for regression problems (i.e., predicting continuous outcomes) because of its simplicity and high accuracy.

The RF regression algorithm uses the ‘wisdom of the crowds.’ RF takes multiple (but different) regression decision trees and makes them ‘vote.’ Each tree needs to predict. RF regression then calculates the average of all of the predictions.

RF regression is a popular algorithm due to its many benefits in production settings: Extremely high accuracy. Random forest regression achieves extremely high accuracies thanks to its ‘wisdom of the crowds’ approach. RF usually produces better results than other linear models, including linear regression and logistic regression.

RF is both a supervised learning algorithm and an ensemble algorithm. RF is supervised in that it learns the mappings between inputs and outputs during training. Ensemble algorithms combine other machine learning algorithms to perform more accurate predictions than any underlying algorithm could on its own. In the case of RF, it ensembles multiple decision trees into its final decision, for a given input. RF regression uses the average of those predictions as its ‘final’ output (Breiman, 2001).

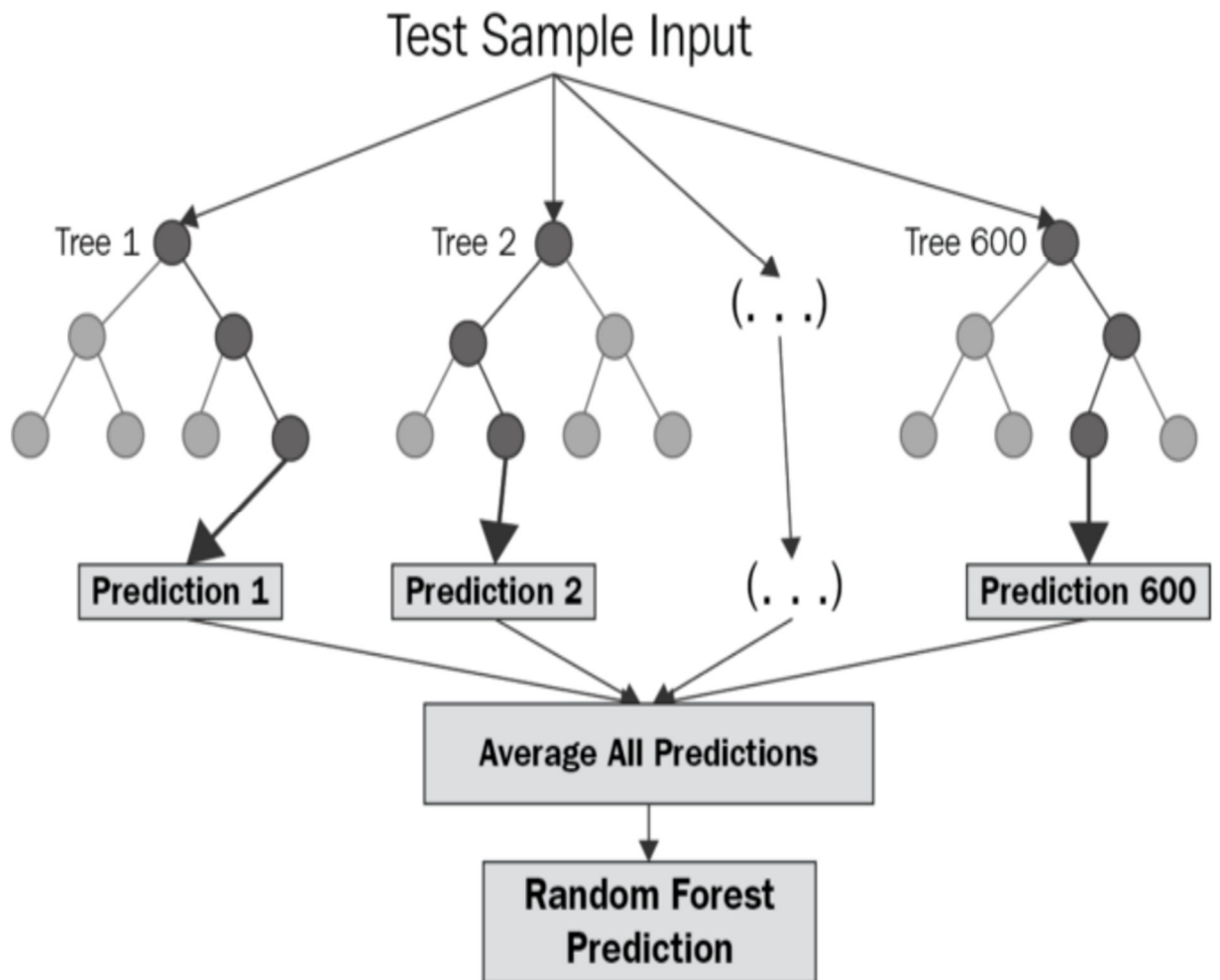


Figure 5.1 Random Forest Prediction trees (Breiman, 2001)

Hyperparameter finds an optimal number for max_depth. More trees usually mean higher accuracy at the cost of slower learning. If we wish to speed up our random forest, lower the number of estimators. If we want to increase the accuracy of our model, increase the number of trees (Kyungsu & Hanguk, 2019).

In this study, the Random Forest model was built to predict occupational accident types using a random forest (RF) algorithm. The accuracy score of the RF model for this study was 86 %. The Random Forest algorithm was selected as it is the best fit model for predicting injury rate because the algorithm uses bootstrap and bagging to avoid the noise and biases one encounters in using a decision tree.

Injury prediction is a dynamic process where enablers, directly and indirectly, affect the occurrence of injuries. Some of these factors that could contribute to injuries are

environmental factors, human factors, and working conditions. The prediction model would capture the dynamic nature of the working environment, activity type, working hours, number of injuries, and injury rate (Yu Zhang et al., 2018).

A machine learning framework is presented to predict injury frequency. Predictive models, including regression trees and Random Forests, are used to identify the injury frequency rate probabilistically. High prediction accuracies of 86% are achieved.

Development of a new model for predicting injury rate using random forests (RFs), a data-driven machine learning technique. The best-performing RF model achieved a mean absolute error (MAE) of 35.0415 min, Khaled Hamad et al., (2020).

To demonstrate that random forest models trained on injury rate samples can accurately predict relevant outcomes. Injury data from the 2009–2018 NCS Sample were used to develop random forest machine learning models to predict injury rates. This study demonstrates that machine learning models may suitably predict the injury rate for oil and gas work environment based on activity type, work hours worked, number of injuries, etc.

The secondary data used for developing the system model has been used from, Injuries in permanently placed facilities.

The Python code for the model development has been shown below:

```

In [10]: # -*- coding: utf-8 -*-
        """
        @author: Desalegn
        """

import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
from sklearn.preprocessing import OneHotEncoder

from sklearn.model_selection import train_test_split
from sklearn.model_selection import GridSearchCV
from sklearn.ensemble import RandomForestRegressor
from sklearn.metrics import r2_score

# import data
df = pd.read_csv('Data-1.csv')

### One Hot Encoding
# import encoder
cat_enc = OneHotEncoder(handle_unknown='ignore')

# encode Activity column
enc_df = pd.DataFrame(cat_enc.fit_transform(df[['Activity']]).toarray())

### Merging data frames df + enc_df

reduced_df = df.drop(['Activity'], axis=1) # create a new data frame dropping the activity column as it is hot encoded

final_df = enc_df.join(reduced_df).to_numpy() # merge both dataframes

### Data Preparation for ML

X = final_df[0,:7] # Features: Year, Activity, Work-Hours, Injuries
y = final_df[0,-1] # Labels: Injury-rate

# Create train and test dataset with an 80:20 split
X_train, X_test, y_train, y_test = train_test_split(X,y,test_size=0.2,random_state = 0,shuffle = False)

# Further divide training dataset into train and validation dataset with an 80:20 split
X_train, X_val, y_train, y_val = train_test_split(X_train,y_train,test_size=0.2,random_state = 0, shuffle = False)

```

```

### Hyperparameter tuning

# Random Forest
param_list1 = {"n_estimators": [10,30,50,70], "max_depth": [10,20,30]}
RFR_model = RandomForestRegressor(random_state = 0)
grid_search1 = GridSearchCV(RFR_model, param_grid=param_list1 , cv=10, scoring='r2' , n_jobs=4).fit(X_train,y_train)

print("Best parameters RandomForest:", grid_search1.best_estimator_)
print("Best score RFR:", grid_search1.best_score_)

### Function for running ML models

def evaluate_model(rf, X_train, X_val, X_test, y_train, y_val, y_test):
    rf.fit(X_train, y_train)
    validation = rf.predict(X_val)
    predictions = rf.predict(X_test)

    print(f'R2_val = {r2_score(y_val,validation)}')
    print(f'R2 = {r2_score(y_test,predictions)}')

plt.figure(figsize=(6,6))

```

```

# function to plot results
plt.scatter(y_test,predictions, s=2, c="black",label="Data sample", alpha=1)
plt.plot([0,np.max([y_test,predictions])],[0,np.max([y_test,predictions])],c="red", linewidth=1, linestyle="-.", label="perf")
plt.xlabel("Truth")
plt.ylabel("Model")
plt.legend()
plt.grid()
plt.text(0.061, 0.001, f'$R^2$ = {np.round(r2_score(y_test,predictions),3)}')

return

#%% Random Forest

rf = RandomForestRegressor(n_estimators = 30, random_state = 0,max_depth=10)

evaluate_model(rf, x_train, x_val, x_test, y_train, y_val, y_test)

Best parameters RandomForest: RandomForestRegressor(max_depth=10, n_estimators=30, random_state=0)
Best score RFR: -35.04149739037091
R2_val = 0.9256449978006008
R2 = 0.8567833226739032

```

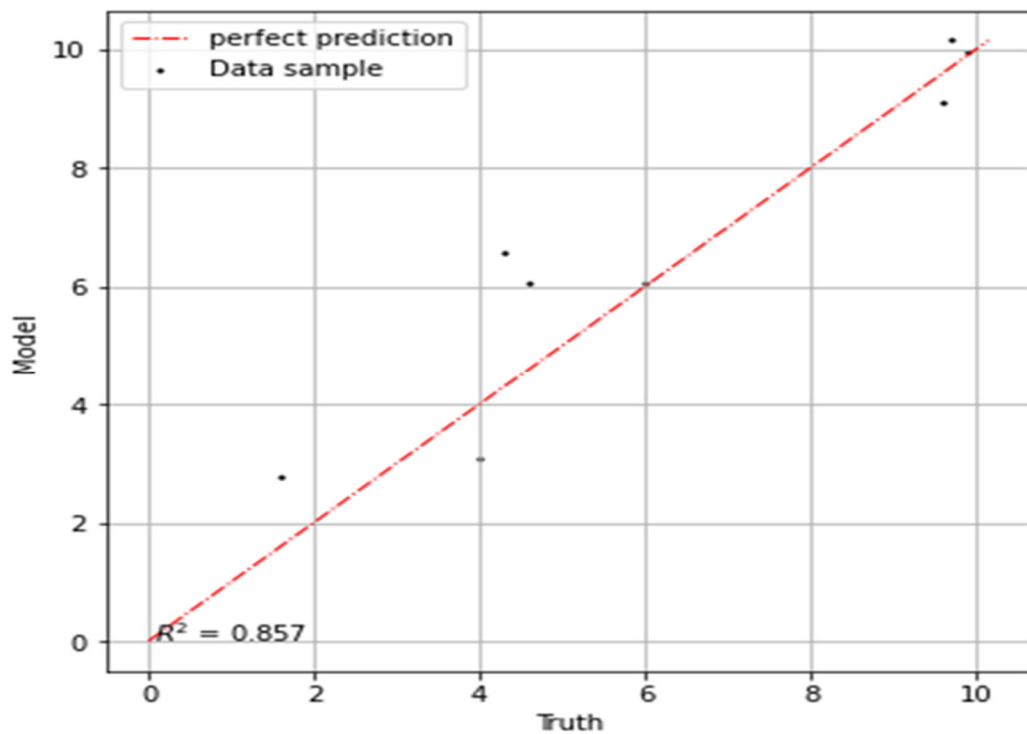


Figure 5.2 Injury Prediction RF Model

5.3 Chapter Summary

In this study, the Random Forest model was built to predict occupational accident types using a random forest (RF) algorithm. The accuracy score of the RF model for this study was 86 %. The RF prediction model was based on ten years (2009-2018) secondary data from Operator X Company.

Chapter Six

6. Contribution to Body of Knowledge

Based on primary data, this dissertation research found that the hand is the most injured body part. This is in line with secondary data findings. To eliminate and minimize the high frequency of hand injury, the author of this study developed a conceptual model. This Hand cycle could positively impact hand injury and contribute to business performance by creating a safe working culture and climate for the workforce. Oil and Gas field personnel validated the conceptual model. It verified the model as a model easy to use. It made aware the performer of the job use the most valuable, intricate, and non-replaceable body part, HAND, wisely and safely without injury.

It is known that lean thinking has eight well-defined wastes. This study identified safety-related incidents as the 10th Waste related to Safety Incidents. When there is a safety incident, the common trend is operation stops, and investigation mandated, which results in safety incident waste. This is an excellent indicator to top management that 'good safety is good business and vice versa.' The misconception by management taking safety as a cost-incurring activity needs to change. Safety needs to be engrained in the overall process, and quality is not different from productivity.

Chapter Seven

7. Conclusion & Recommendation

7.1 Conclusion

Most safety researches focus on safety incidents caused by unsafe conditions, while 90% of incidents happen due to unsafe acts. Most O&G incidents happen when employees disregard safety rules (Unsafe acts), and management ignores the presence of unsafe conditions. Therefore unsafe acts and conditions are the immediate (direct) causes of accidents. On the other hand, the physical and mental condition of the employee, as well as environmental forces and supervisory safety performance, are the contributory (indirect) causes of accidents, Seyyed & Zahra, (2012).

Compliance with safety regulations is insufficient to eliminate accidents and assure a safe environment (Gambetese and Pestana 2014). Improving safety in oil and gas remains a priority in almost every country worldwide since the oil and gas industry stands out among all other industries as the main contributor to severe and fatal accidents, Ghosh & Young-Corbett, (2009).

Safety-related incidents, accidents, and near misses could be attributed to different factors:

Individual factors: Employees do not possess adequate technical knowledge, experience, competency, and training in relation to their work and the existing workplace hazards—low level of employee involvement in continuous safety system improvement.

⇒ Poor experience and unfamiliarity with work nature, workplace, and used tools, particularly for newly recruited workers. Poor onboarding for new employees, complacency for experienced employees, and sticking to the old way of doing safety, mainly focusing on compliance to safety requirements.

⇒ Using the improper tool for the wrong task. Sometimes with poor work planning and job execution using the wrong tools deemed unsuitable for the job.

⇒ Negative attitudes & habits of employees for safety practice, assuming it is something the top management requires in a top-down chain of command.

-Job factors:

⇒ As the oil and gas prices sustained long-term all-time low, they usually project pressure on everyone involved for better KPI, which sometimes creates workload increases the work pressure that negatively affects employees' safety behavior (Amponsah-Tawaih, Adu, 2016). This may lead to potential workplace injuries.

Organizational factors:

⇒ The unresponsiveness of the management to HSE issues. The current practice in safety system management is the reactive management approach giving safety issues attention whenever an incident happens. No practice of taking safety systems differently, to build on the positive developments of the safety system and continuously improve with every player's involvement.

⇒ Negative peer group pressure. As the work environment is becoming diverse regarding employees' background explained, years of experience, educational background, multinational composition, and negative peer pressure could lead to safety incidents.

⇒ Lack or absence of coordination in the workplace. The oil and gas offshore field activity comprises operators, suppliers, contractors, regulators, and other players. Usually, the synergy among these players is not visible, especially regarding continuous improvement in safety management.

⇒ Poor working procedure of the conducted works. Fortunately, the oil and gas industry has a good record of established working procedures. Still, from time to time, in the name of completing projects within deadlines, people use shortcuts and procedures bypassed.

⇒ Lack of supervision. Safety leadership is still missing in the sector, as management and frontline supervisors engage in safety matters only during incidents. Otherwise, a safety system is not embedded in business work processes to add value.

⇒ Poor safety culture. Everything comes to the working safety culture. Safety culture is how activities are performed when no one is watching. If safety were considered the responsibility of everyone, safety would not be a one-time effort; it could be a culture in the work setting.

⇒ Uncontrolled workplace hazards. Unfortunately, the oil and gas upstream work environment is the most hazardous workplace. Unidentified workplace hazards

could lead to incidents. Before executing the job, there needs to be a persistent hazard hunt, risk management, mitigation, and control mechanism (El Bouti & Allouch, (2017).

In 21-century corporate organizations, sustainability expressed in terms of social, economic, environmental, and safety aspects are becoming the norm. By its very nature, offshore oil and gas exploration and production activities have a high impact on the environment, social, workforce, and ecosystem, and the consequence of accidents on an organization in particular. Thus, developing an accident-free working environment is in an organization's best interest to pursue business sustainably and acquire the consent of the interest groups (government regulatory body, environmental group, local community, workers union, other industries such as fishing, etc.)

Work environment safety in the context of offshore oil and gas drilling and production is a result of workforce safety culture, offshore installations integrity, company HSE best practices, regulatory body standards, safety management systems, organizational problem-solving culture, employee engagement and involvement, and continuous HSE improvement culture collaborating and players along the value chain.

The most common non-fatal injuries in the O&G upstream sector include:

- Hand injury
- Lacerations
- Fractures and broken bones
- Burns
- Internal or external chemical burns
- Neck injuries
- Spinal cord injuries, etc.

The following are the most common causal factors that appear regularly in workplace incidents from the oil and gas upstream context:

- Inadequate training/competence
- Improper decision-making and frontline employees' low involvement in safety matters.
- Work standards/procedures bypassed

- Inadequate supervision and reactive measures in safety issues
- Inadequate hazard identification or risk assessment
- Focus on compliance instead of continuous safety system improvement
- Lack of focus, improper position (line of fire)

7.2 Recommendation

For Management

- Never base safety performance on an employee's number of safety incidents. As this could result in under-reporting safety incidents.
- Do not just focus on incidents that went wrong; it is a learning benchmark to focus on safety systems that have gone right also.
- Do not make safety improvement a one-time endeavor that you would start when an incident happens; it should be a continuous improvement process ingrained in the business processes.
- All levels of management need to be actively involved in safety matters instead of leaving safety for the safety officers.
- Management leadership in safety is crucial to get everyone involved in safety efforts.
- Management should refrain from overloading employees, which usually happens to meet deadlines, which could result in stress and incidents, and accidents.
- Safety systems must be designed considering human error to result in fail-safe.
- Management needs to center every safety-related decision on 'Respect for employees.'
- Establish proper on-boarding and induction for new employees to ensure new employees become aware of hazards at the workplace.
- Create a workplace ergonomically suitable for employees

For Employees

- Employees have the right to stop the job if they deem it unsafe.
- Employees have the right to speak up when they face unsafe acts and conditions.

- Employees are best placed on hunting hazards and continuously improve safety systems in their work environment.
- Your safety is in your hand and your responsibility, take it seriously and be actively involved.
- Good housekeeping tidy and clean work environment enhance good safety practices.
- Never take shortcuts; take the time to properly risk analyze and take all safety measures the job requires.
- Isolate hazardous energy sources using Lockout, tag-out (LOTO) practices.
- As this dissertation conceptual modeling dictates, use proper body positioning, particularly your hand. The abbreviation HAND has been used as a metaphor to make every employee focus on the task at hand with high attention. HAND stands for; **H**= Hazard, **A**=Awareness, **N**= Neutralization, **D**= Deliberation/Decision.

7.3 Future Research Areas

The main focus of this dissertation study has been the oil and gas industry safety system. The industry has a very strict policy on data usage and confidentiality. In line with this, getting primary data was a big challenge. Future studies could be based on big data.

Artificial intelligence (AI) has been an innovative business tool. In this dissertation, the Machine learning (ML) algorithm, Random Forest, has been used to predict injury rates in the upstream oil and gas sector. Future research could use different algorithms to compare the prediction accuracy.

This dissertation specifically focused on the safety practices of the upstream oil and gas sector targeting the North-sea sector. Future research could compare and contrast safety practices in different regions of the globe, for example, safety practices in the Middle East and safety practices in Northern Europe.

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Annex A Major Accomplishment during the Ph.D. study

Publications

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Community Services

- Board member of Ethiopian Community in Norway, Rogaland.
- While commuting to Ethiopia every month, connect families in Norway and Ethiopia, bringing messages and other stuff.

Annex B Oil and Gas safety-related data

Table B1: Events in chains for different types of units, WOAD

Event in Chain	Fixed Units	Mobile Units	Other
Anchor/mooring failure	3	196	22
Blowout	159	196	4
Breakage or fatigue	233	326	200
Capsizing, overturn, toppling	164	107	14
Collision, not offshore units	111	76	64
Collision, offshore units	98	204	76
Crane accident	303	325	22
Explosion	120	58	14
Falling load / Dropped object	538	547	27
Fire	732	252	46
Grounding	0	67	17
Helicopter accident	37	18	4
Leakage into hull	7	68	9
List, uncontrolled inclination	12	101	4
Loss of buoyancy or sinking	37	97	132
Machinery/propulsion failure	0	27	6
Other	116	92	238
Out of position, adrift	1	221	32
Release of fluid or gas	1314	299	280
Towline failure/rupture	1	94	15
Well problem, no blowout	253	299	4

Chronological Distribution of accidents in the WOAD database

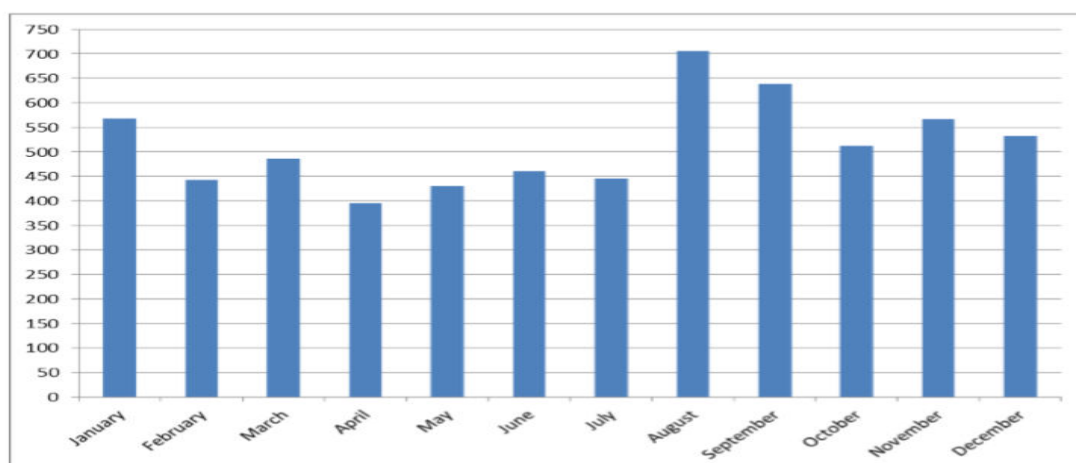


Fig. B1 Annual Distribution of accidents in the WOAD database

Table: B2 provides the number of accidental events for the different types of Unit, WOAD.

Type Of Unit	Accidents	Incidents / Hazardous situation	Near miss	Insignificant
Barge (not drilling)	41	20	2	0
Concrete structure	81	419	74	136
Drill barge	65	22	0	2
Drill ship	91	65	3	4
Drilling tender	10	4	0	1
Flare	1	0	0	1
FPSO/FSU	10	68	8	23
Helicopter-Offshore duty	238	17	13	3
Jacket	716	889	127	252
Jackup	552	210	13	33
Lay barge	21	14	0	1
Loading buoy	13	19	2	5
Mobile unit(not drill.)	18	3	0	0
Other	0	2	0	1
Other/Unkn. fixed struct	3	3	0	1
Pipeline	139	111	1	4
Semi-submersible	277	626	147	119
Ship, not drilling or production	6	27	1	8
Submersible	19	5	0	1
Subsea install./complet.	4	6	0	2
Tension leg platform	13	132	22	29
Well support structure	122	36	2	2

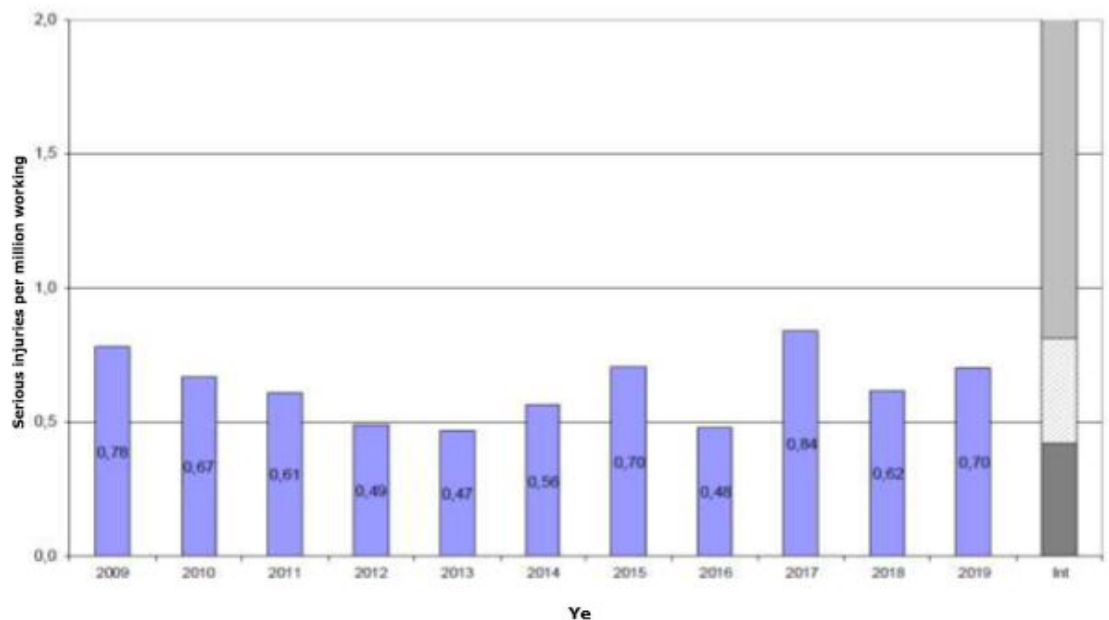


Fig. B2 Serious personal injuries per million working hours, NCS, Ptil.no, RNNP, (2019)

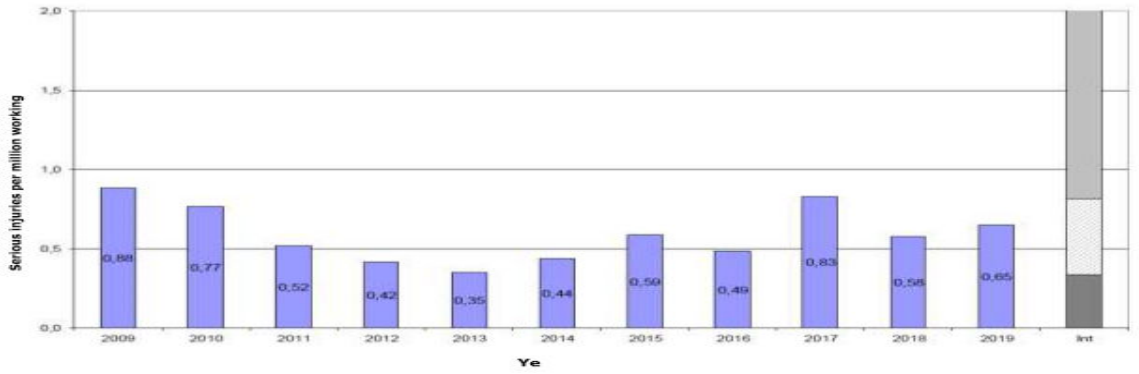


Fig. B3 Serious personal injuries on production facilities per million working hours, NCS, Ptil.no, RNNP, (2019)

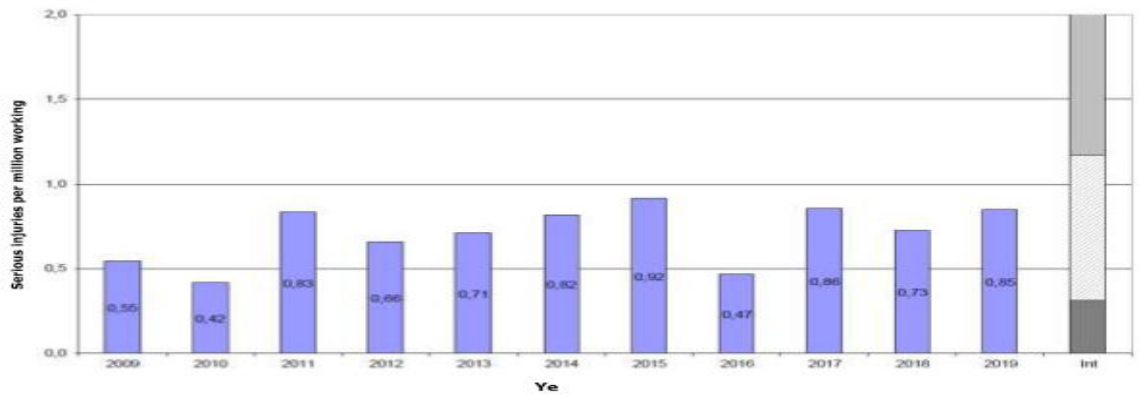


Fig. B4 Serious personal injuries per million working hours, mobile facilities, NCS, Ptil.no, RNNP, (2019)

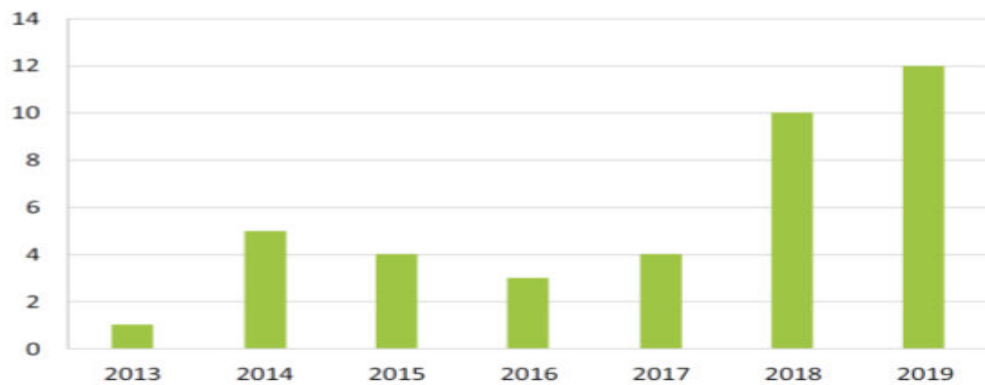
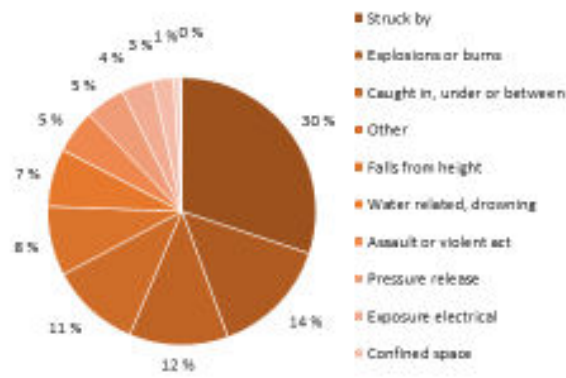


Fig. B5 Total No. of falling objects causing personal injury, in 2013-2019, NCS, Ptil.no, RNNP, (2019).

Work Related fatalities by category 2005 to 2015 inclusive



Work Related fatalities by activity 2005 to 2015 inclusive

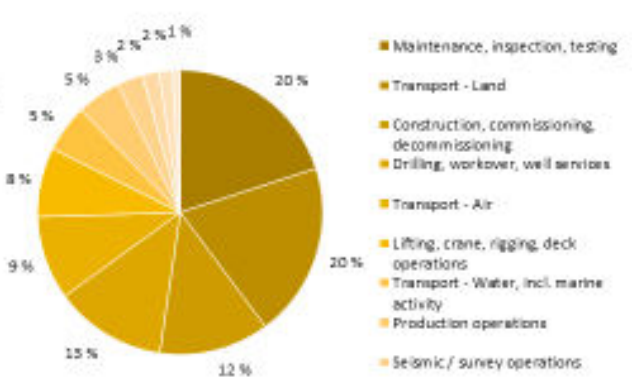


Fig. B6 Fatalities by activity and category, IOGP, (2016).

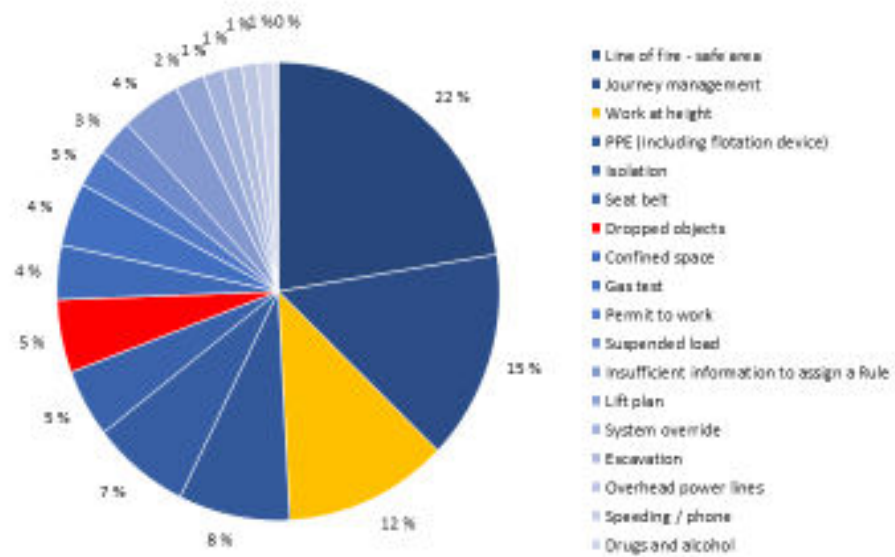


Fig. B7 Work-related fatalities by life-saving rules, 2015, IOGP, (2016)

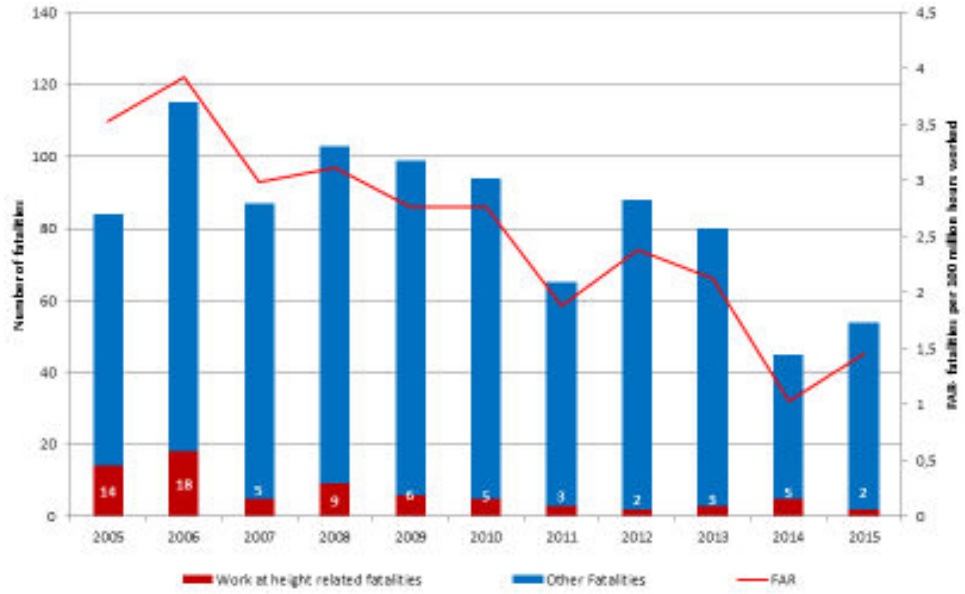


Fig. B8 No. of fatalities and fatal incident rate, 2005-2015, highlighting work at height-related fatalities, IOGP, (2016)

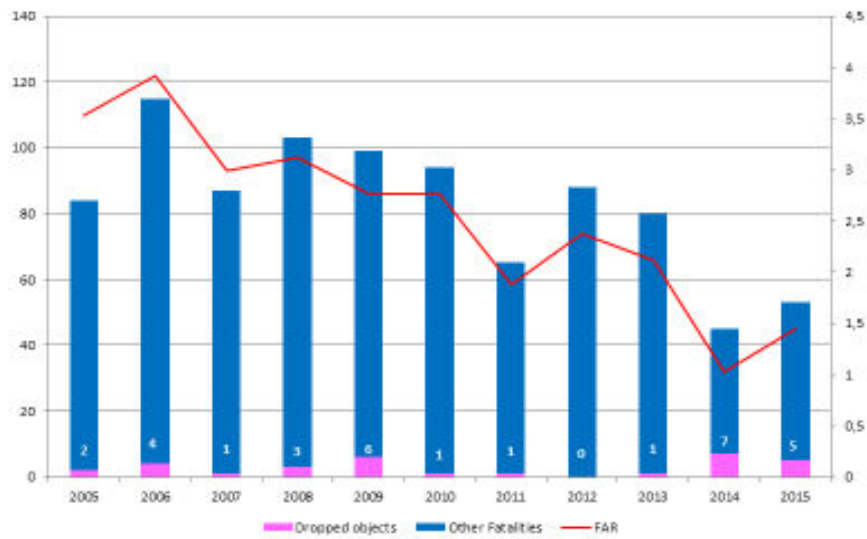


Fig. B9 No. of fatalities and fatal incident rate 2005-2015, dropped object-related fatalities, IOGP, (2016)

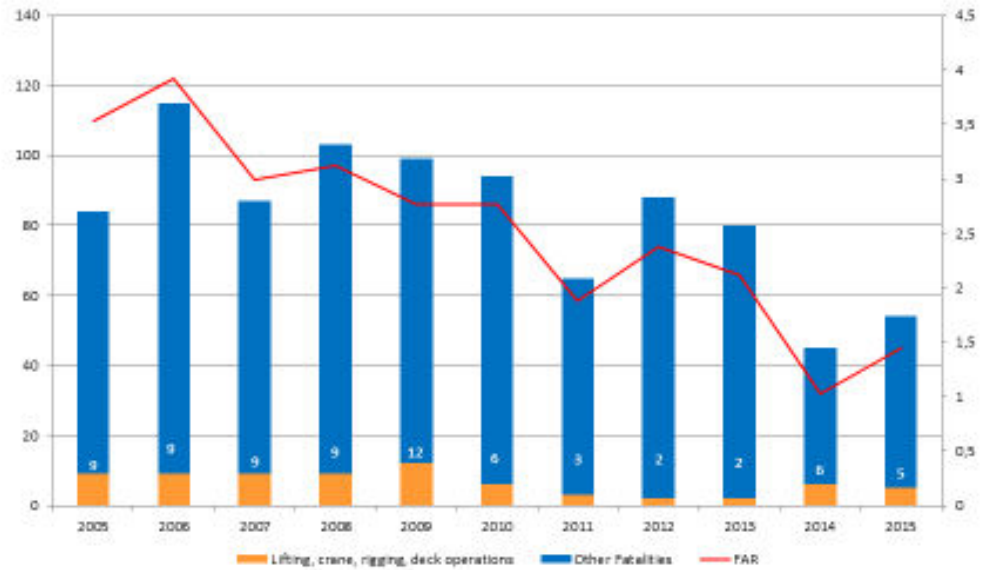


Fig. B10 No. of fatalities and fatal incident rate, 2005-2014, lifting, crane rigging, deck operations related fatalities, IOGP, (2016)

Table B3: Total recordable injury rate by country (2017-2019)

Note: data is only included in TRIR calculations where medical treatment cases are reported.

Countries with less than 50,000 reported work hours, or fewer than two companies reporting, are excluded.

Total recordable injury rate (TRIR)

Region	Country	2017	2018	2019
Africa	Namibia		0.00	15.87
Africa	Gabon	1.24	1.25	1.75
Africa	Senegal	2.40	2.20	1.74
Africa	Tunisia	0.93	0.89	1.57
Africa	Kenya	0.00	0.55	0.99
Africa	Mozambique	0.79	1.36	0.84
Africa	Angola	0.60	0.42	0.75
Africa	Algeria	1.42	1.61	0.72
Africa	Equatorial Guinea	0.91	0.76	0.56
Africa	AFRICA AVERAGE	0.48	0.50	0.42
Africa	Ghana	0.86	0.52	0.38
Africa	Egypt	0.28	0.24	0.28
Africa	Congo	0.36	0.30	0.27
Africa	Libya	0.28	0.31	0.22
Africa	Nigeria	0.28	0.34	0.22
Africa	Mauritania	0.53	0.74	0.00
Africa	South Africa	0.00	9.39	0.00
Africa	Tanzania	0.00	0.00	0.00
Africa	Uganda	0.85	0.00	0.00
Africa	Ivory Coast	0.00	0.00	
Africa	Morocco	0.00	0.00	
Africa	São Tomé And Príncipe	2.87		
Asia / Australasia	New Zealand	1.50	3.93	5.35
Asia / Australasia	Australia	1.67	2.01	2.42
Asia / Australasia	Papua New Guinea	1.49	1.07	0.99
Asia / Australasia	Thailand	0.84	0.67	0.92
Asia / Australasia	ASIA / AUSTRALASIA AVERAGE	0.75	0.72	0.60
Asia / Australasia	Myanmar	1.10	0.41	0.60
Asia / Australasia	India	0.17	0.76	0.36

Asia / Australasia	Malaysia	0.54	0.57	0.33
Asia / Australasia	China	0.37	0.33	0.28
Table B3 Cont'd				
Asia / Australasia	Indonesia	0.21	0.26	0.24
Asia / Australasia	Japan	0.96	1.65	0.24
Asia / Australasia	Pakistan	0.54	0.33	0.20
Asia / Australasia	Singapore	0.00	0.15	0.11
Asia / Australasia	Brunei	1.70	0.00	0.00
Asia / Australasia	Vietnam	0.87	0.00	0.00
Asia / Australasia	South Korea	1.29	1.53	
Europe	Denmark	2.72	3.25	3.64
Europe	Germany	3.35	3.69	3.35
Europe	Poland		2.28	2.95
Europe	Norway	2.67	2.62	2.76
Europe	Netherlands	2.50	2.13	2.65
Europe	EUROPE AVERAGE	2.07	2.17	2.28
Europe	UK	1.98	2.35	1.85
Europe	Italy	1.22	0.75	1.81
Europe	Spain	1.05	0.50	1.60
Europe	Romania	0.60	1.09	1.11
Europe	France	0.15	0.74	0.87
Europe	Hungary	2.86	1.32	0.84
Europe	Bulgaria	0.00		0.00
Europe	Cyprus	2.56	0.00	0.00
Europe	Croatia	1.86	1.49	
Europe	Ireland	6.52	0.00	
Europe	Ukraine	0.00	0.00	
Middle East	Kurdistan Region Of Iraq			2.51
Middle East	Turkey	0.00	3.26	1.65
Middle East	Yemen	0.00	0.51	0.75

Table B3 Cont'd

Total recordable injury rate (TRIR)				
Region	Country	2017	2018	2019
Middle East	UAE	0.81	0.45	0.54
Middle East	Qatar	0.55	0.64	0.51
Middle East	MIDDLE EAST AVERAGE	0.55	0.43	0.45
Middle East	Kuwait	0.30	0.31	0.36
Middle East	Oman	0.52	0.56	0.25
Middle East	Iraq	0.36	0.54	0.18
Middle East	Iran	0.00	0.00	
North America	Canada	2.24	2.20	1.74
North America	USA	1.88	1.94	1.67
North America	NORTH AMERICA AVERAGE	1.96	2.00	1.66
North America	Mexico	1.96	2.36	0.80
Russia & Central Asia	Turkmenistan	0.00	0.00	0.89
Russia & Central Asia	Azerbaijan	0.43	0.26	0.63
Russia & Central Asia	Kazakhstan	0.50	0.66	0.61
Russia & Central Asia	RUSSIA & CENTRAL ASIA AVERAGE	0.44	0.54	0.58
Russia & Central Asia	Russia	0.29	0.19	0.28
South & Central America	Argentina	1.14	2.66	2.34
South & Central America	Peru	1.18	1.21	1.44
South & Central America	SOUTH & CENTRAL AMERICA AVERAGE	1.44	1.64	1.35
South & Central America	Trinidad & Tobago	0.97	1.66	0.97
South & Central America	Brazil	1.51	1.34	0.95
South & Central America	Guyana	1.08	0.00	0.89
South & Central America	Colombia	2.00	0.81	0.70
South & Central America	Venezuela	0.44	0.24	0.70
South & Central America	Ecuador	1.27	2.42	0.58
South & Central America	Bolivia	1.62	0.73	0.35
South & Central America	Suriname	0.00	1.52	-
South & Central America	Uruguay	-	0.00	-

Table B4: Causal factors assigned to high potential events (2010 - 2019)

Causal factor	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
PROCESS (CONDITIONS) : Organisational : Inadequate hazard identification or risk assessment	51	30	69	52	37	66	116	54	48	60
PROCESS (CONDITIONS) : Organisational : Inadequate work standards/procedures	44	22	59	52	36	40	80	49	36	38
PEOPLE (ACTS) : Inattention/Lack of Awareness :	25	26	41	30	25	33	81	36	29	38
PROCESS (CONDITIONS) : Organisational :	22	23	42	33	27	21	39	22	15	30
PROCESS (CONDITIONS) : Organisational :	33	21	49	29	26	25	44	26	28	29
PROCESS (CONDITIONS) : Organisational :	24	18	40	36	21	33	47	30	33	29
PROCESS (CONDITIONS) : Tools, Equipment, tools/equipment/materials/products	21	15	30	35	16	19	57	21	20	29
PROCESS (CONDITIONS) : Tools, Equipment, design/specification/management of change	19	18	19	38	25	30	68	40	33	24
PROCESS (CONDITIONS) : Tools, Equipment, maintenance/inspection/testing	26	13	41	43	31	37	54	28	27	23
PROCESS (CONDITIONS) : Protective Systems : Inadequate/defective guards or protective barriers	12	11	26	28	12	18	51	14	16	22
PEOPLE (ACTS) : Use of Tools, Equipment, Materials and Products : Improper use/position of tools/equipment/materials/products	10	19	24	25	17	21	58	23	20	22
PEOPLE (ACTS) : Following Procedures : Violation unintentional (by individual or group)	32	19	28	13	19	25	58	18	16	21
PEOPLE (ACTS) : Use of Protective Methods :	3	9	15	9	14	14	62	13	10	13
PROCESS (CONDITIONS) : Protective Systems : devices	14	19	8	17	9	15	17	7	10	13
PEOPLE (ACTS) : Following Procedures : Violation	10	9	8	12	12	14	24	9	4	12
PEOPLE (ACTS) : Following Procedures : Improper	10	3	13	9	7	12	35	8	14	10
PEOPLE (ACTS) : Following Procedures : Improper	6	10	12	6	7	6	34	3	5	9
PEOPLE (ACTS) : Inattention/Lack of Awareness : concerns/stress	17	10	24	14	10	8	48	21	16	8
PEOPLE (ACTS) : Use of Tools, Equipment, Materials and Products : Improper use/position of tools/equipment/Inadequate energy isolation	6	3	5	3	2	9	19	6	10	7
PEOPLE (ACTS) : Use of Protective Methods :	9	15	32	12	11	9	40	11	12	7
PEOPLE (ACTS) : Use of Protective Methods : Inadequate use of safety systems	2	12	20	9	5	10	19	7	15	6
PROCESS (CONDITIONS) : Organisational : Failure to report/learn from events	6	2	3	8	6	7	13	4	5	6
PEOPLE (ACTS) : Use of Protective Methods : Personal Protective Equipment not used or used improperly	7	3	8	4	5	11	9	3	4	5
PEOPLE (ACTS) : Use of Protective Methods : Disabled or removed guards, warning systems or safety devices	1	5	4	2	4	1	9	1	1	5
PROCESS (CONDITIONS) : Organisational : Poor leadership/organisational culture	17	10	13	11	10	13	15	14	13	5
PROCESS (CONDITIONS) : Work Place Hazards : Hazardous atmosphere (explosive/toxic/asphyxiant)	6	5	6	3	4	5	17	1	6	4
PROCESS (CONDITIONS) : Protective Systems : Inadequate/defective Personal Protective Equipment	3	1	2	4	0	3	2	3	1	3
PEOPLE (ACTS) : Inattention/Lack of Awareness : Fatigue	4	4	1	1	2	2	5	2	3	3
PROCESS (CONDITIONS) : Work Place Hazards : Congestion, clutter or restricted motion	3	3	5	4	0	2	11	5	4	3
PROCESS (CONDITIONS) : Work Place Hazards : Storms or acts of nature	0	3	3	5	5	2	17	1	3	1
PEOPLE (ACTS) : Following Procedures : Overexertion or improper position/posture for task	3	1	1	2	2	1	1	2	2	1
PEOPLE (ACTS) : Following Procedures : Work or motion at improper speed	3	3	5	2	4	2	4	3	1	1
PEOPLE (ACTS) : Inattention/Lack of Awareness : Acts of violence	0	1	2	0	1	2	2	0	0	0
PEOPLE (ACTS) : Inattention/Lack of Awareness : Use of drugs or alcohol	0	0	0	0	0	0	1	0	0	0
PROCESS (CONDITIONS) : Work Place Hazards : Inadequate surfaces, floors, walkways or roads	6	2	5	4	4	2	15	4	3	0
PROCESS (CONDITIONS) : Protective Systems :	1	3	4	3	1	4	4	1	4	0

Causal factors are listed in order of frequency for 2019. The top 10 causal factors assigned to high potential events for each year are highlighted. 2019: 2 causal factors were equal 10th with 22 assigned events (11 factors are highlighted)
 2018: 3 causal factors were equal 10th with 16 assigned events (12 factors are highlighted)
 2017: 2 causal factors were equal 10th with 21 assigned events (11 factors are highlighted)

Table B5: Causal factors assigned to fatal incidents (2010 & 2019)

Causal factor	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
PROCESS (CONDITIONS) : Organisational :	30	15	17	13	18	11	10	10	15	9
PEOPLE (ACTS) : Inattention/Lack of Awareness :	14	16	11	16	13	10	13	9	14	9
PROCESS (CONDITIONS) : Organisational :	18	18	16	14	13	9	9	12	17	7
PEOPLE (ACTS) : Following Procedures : Improper	16	9	13	12	14	6	11	7	13	7
PEOPLE (ACTS) : Following Procedures : Violation	12	9	13	11	9	9	2	6	5	5
PROCESS (CONDITIONS) : Protective Systems :	7	11	6	10	6	4	2	8	4	4
PEOPLE (ACTS) : Inattention/Lack of Awareness : concerns/stress	7	7	5	4	3	4	6	4	1	4
PEOPLE (ACTS) : Use of Protective Methods :	7	8	4	6	4	5	5	5	4	4
PROCESS (CONDITIONS) : Organisational :	10	8	15	15	18	8	4	4	3	3
PROCESS (CONDITIONS) : Organisational :	12	9	6	8	6	6	3	1	5	3
PROCESS (CONDITIONS) : Organisational :	13	10	13	21	16	11	6	4	11	3
PROCESS (CONDITIONS) : Organisational : Failure	3	1	0	1	3	0	2	0	2	3
PEOPLE (ACTS) : Use of Protective Methods : Equipment or materials not	6	4	4	8	3	3	2	1	4	2
PEOPLE (ACTS) : Following Procedures : Improper	8	2	7	4	1	2	2	0	6	2
PEOPLE (ACTS) : Use of Tools, Equipment, Materials and Products : Servicing of energized equipment/inadequate energy isolation	3	0	3	3	4	3	2	3	2	2
PEOPLE (ACTS) : Use of Protective Methods : improperly	1	6	4	7	8	6	1	2	1	2
PROCESS (CONDITIONS) : Protective Systems : used Inadequate defective Personal Equipment	0	5	5	4	0	5	0	1	0	2
PROCESS (CONDITIONS) : Tools, Equipment, tools/equipment/materials/products	4	5	7	9	0	5	3	5	2	1
PROCESS (CONDITIONS) : Tools, Equipment, & Produ design/specification/management of change	10	5	7	4	4	7	1	2	3	1
PEOPLE (ACTS) : Use of Tools, Equipment, Materials tools/equipment/materials/products	9	6	7	10	6	4	3	4	4	1
PROCESS (CONDITIONS) : Protective Systems : devices	5	6	5	5	5	4	2	1	2	1
PEOPLE (ACTS) : Following Procedures : Violation intentional (by individual or group)	12	4	4	2	5	4	2	2	5	1
PEOPLE (ACTS) : Use of Protective Methods : systems	5	4	9	7	2	2	1	1	4	1
PEOPLE (ACTS) : Inattention/Lack of Awareness :	0	1	1	0	0	2	1	2	0	1
PEOPLE (ACTS) : Following Procedures : Work or Inadequate use of safety systems	0	2	1	2	1	3	2	4	1	1
PROCESS (CONDITIONS) : Tools, Equipment, maintenance/inspection/testing	4	6	5	9	5	3	4	2	6	0
PEOPLE (ACTS) : Use of Protective Methods : safety devices Materials & Products :	2	2	2	3	2	0	1	0	2	0
PROCESS (CONDITIONS) : Organisational : Poor	9	4	4	6	3	2	0	6	3	0
PROCESS (CONDITIONS) : Work Place Hazards : Disabled or removed guards, warning systems or	1	1	2	2	0	1	1	1	0	0
PROCESS (CONDITIONS) : Work Place Hazards :	2	4	4	0	0	3	1	1	2	0
PROCESS (CONDITIONS) : Work Place Hazards :	2	5	0	2	0	1	1	1	1	0
PEOPLE (ACTS) : Following Procedures :	3	0	1	0	0	0	1	1	1	0
PEOPLE (ACTS) : Inattention/Lack of Awareness : Constitutionally/Lack of Awareness	6	1	2	0	0	0	0	2	0	0
PEOPLE (ACTS) : Inattention/Lack of Awareness :	0	0	1	0	0	0	0	1	0	0
PROCESS (CONDITIONS) : Work Place Hazards : Dropped or on work place hazards posture for task Acts of violence Use of drugs or alcohol Inadequate surfaces, floors, walkways or roads Inadequate security provisions or systems	7	4	3	1	4		3	0	0	0

Causal factors are listed in order of frequency for 2019. The top 10 causal factors assigned to fatal incidents for each year are highlighted. 2017: 5 causal factors were equal 10th with 4 assigned incidents (14 factors are highlighted) 2016: 4 causal factors were equal 10th with 3 assigned incidents (13 factors are highlighted) 2014: 3 causal factors were equal 9th with 6 assigned incidents (11 factors are highlighted) 2013: 2 causal factors were equal 10th with 9 assigned incidents (11 factors are highlighted) 2012: 4 causal factors were equal 9th with 7 assigned incidents (12 factors are highlighted)

TableB6: IOGP Life-Saving Rules allocated to fatal incidents (2019)

Life-Saving Rule	Fatal incidents
Bypassing safety controls	1
Confined space	0
Driving	3
Energy isolation	3
Hot work	0
Line of fire	6
Safe mechanical lifting	3
Work at height	0
Work authorisation	3
Other issue	0
Insufficient information to assign a Rule	1
Unspecified	2

TableB7: Severity of lost workday cases by region (2015 - 2019)

Region	2015	2016	Average days lost per LWDC	2018	2019
Africa	42.7	33.1	44.6	29.8	36.1
Asia / Australasia	27.7	39.5	39.4	61.8	37.5
Europe	38.8	45.3	32.5	42.7	62.5
Middle East	24.6	62.2	35.8	43.5	30.3
North America	87.8	25.1	25.2	32.5	41.8
Russia & Central Asia	70.8	55.3	126.0	90.5	85.0
South & Central America	55.9	93.4	51.6	60.7	59.4
OVERALL	54.0	61.4	42.5	51.5	50.9

TableB8: Work hours reported by region (2010-2019)

Region	Thousand work hours									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Africa	562,121	558,573	600,478	595,637	580,464	543,205	444,534	489,592	537,130	480,700
Asia / Australasia	725,171	609,466	741,523	919,063	1,077,835	924,392	745,095	595,521	531,067	594,527
Europe	308,954	344,842	384,950	399,584	385,847	343,123	273,984	248,856	250,880	275,861
Middle East	676,337	690,171	666,915	637,244	607,954	653,049	607,678	754,753	756,946	675,784
North America	295,339	400,902	560,027	590,089	1,025,254	864,115	325,869	326,804	367,241	369,476
Russia & Central Asia	461,743	439,340	363,662	239,832	247,816	249,560	166,000	235,205	220,906	246,248
South & Central America	381,479	412,784	373,485	389,097	440,789	141,872	332,461	348,308	402,180	395,756
OVERALL	3,411,144	3,456,078	3,691,040	3,770,546	4,365,959	3,719,316	2,895,621	2,999,039	3,066,350	3,038,352

Table B9: Summary of 2019 data by function

Function	Data type	Operations	Hours worked (thousands)	Fatalities	LWDCs (number)	RWDCs (number)	MTCs (number)	FA R	TRI R	LTI R
Exploration	Company	Onshore	18,188	0	12	2	1	0.00	0.82	0.66
Exploration	Company	Offshore	446	0	1	0	0	0.00	2.24	2.24
Exploration	Contractor	Onshore	10,466	0	9	6	12	0.00	2.58	0.86
Exploration	Contractor	Offshore	8,779	0	3	1	2	0.00	0.68	0.34
Exploration	SUBTOTAL	SUBTOTAL	37,879	0	25	9	15	0.00	1.29	0.66
Drilling	Company	Onshore	33,665	0	8	4	12	0.00	0.71	0.24
Drilling	Company	Offshore	7,209	0	0	1	4	0.00	0.69	0.00
Drilling	Contractor	Onshore	210,284	2	102	125	247	0.95	2.26	0.49
Drilling	Contractor	Offshore	147,872	2	72	65	75	1.35	1.45	0.50
Drilling	SUBTOTAL	SUBTOTAL	399,030	4	182	195	338	1.00	1.80	0.47
Production	Company	Onshore	261,018	1	58	34	71	0.38	0.68	0.23
Production	Company	Offshore	99,013	2	51	28	52	2.02	1.34	0.54
Production	Contractor	Onshore	667,115	9	112	128	240	1.35	0.73	0.18
Production	Contractor	Offshore	311,879	4	119	94	208	1.28	1.36	0.39
Production	SUBTOTAL	SUBTOTAL	1,339,025	16	340	284	571	1.19	0.92	0.27
Construction	Company	Onshore	29,967	0	1	0	4	0.00	0.17	0.03
Construction	Company	Offshore	6,628	0	1	0	0	0.00	0.15	0.15
Construction	Contractor	Onshore	463,546	3	51	51	176	0.65	0.61	0.12
Construction	Contractor	Offshore	151,437	0	30	37	83	0.00	0.99	0.20
Construction	SUBTOTAL	SUBTOTAL	651,578	3	83	88	263	0.46	0.67	0.13
Unspecified	Company	Onshore	184,788	0	17	13	41	0.00	0.39	0.09
Unspecified	Company	Offshore	16,336	0	3	1	5	0.00	0.55	0.18
Unspecified	Contractor	Onshore	314,220	2	35	45	121	0.64	0.62	0.12
Unspecified	Contractor	Offshore	95,496	0	18	17	35	0.00	0.73	0.19
Unspecified	SUBTOTAL	SUBTOTAL	610,840	2	73	76	202	0.33	0.57	0.12
TOTAL	Company	Onshore	527,626	1	96	53	129	0.19	0.54	0.18
TOTAL	Company	Offshore	129,632	2	56	30	61	1.54	1.15	0.45
TOTAL	Contractor	Onshore	1,665,631	16	309	355	796	0.96	0.88	0.20
TOTAL	Contractor	Offshore	715,463	6	242	214	403	0.84	1.21	0.35
GRAND TOTAL	TOTAL	TOTAL	3,038,352	25	703	652	1,389	0.82	0.92	0.24

Table B10 Total work hours reported (1985-2019)

Year	Overall	Work hours reported (thousands)	
		Hours company	Hours contractor
1985	655,650	410,409	245,241
1986	544,053	305,637	238,416
1987	602,480	355,578	246,902
1988	616,448	363,530	252,918
1989	655,945	330,970	324,975
1990	720,652	331,986	388,666
1991	940,538	441,141	499,397
1992	944,143	431,139	513,004
1993	919,176	410,474	508,702
1994	871,973	397,258	474,715
1995	840,811	355,695	485,186
1996	911,540	360,149	551,391
1997	1,161,335	389,442	771,893
1998	1,131,229	385,619	745,610
1999	1,197,460	395,141	802,319
2000	1,633,855	571,915	1,061,940
2001	1,976,646	633,039	1,343,607
2002	2,120,829	636,414	1,484,415
2003	2,247,026	663,894	1,583,132
2004	2,290,453	638,739	1,651,714
2005	2,380,670	639,292	1,741,378
2006	2,936,974	734,425	2,202,549
2007	2,912,801	667,986	2,244,815
2008	3,304,168	712,482	2,591,686
2009	3,585,842	822,240	2,763,602
2010	3,411,144	725,673	2,685,471
2011	3,456,078	753,100	2,702,978
2012	3,691,040	759,600	2,931,440
2013	3,770,546	820,856	2,949,690
2014	4,365,959	945,572	3,420,387
2015	3,719,316	896,862	2,822,454
2016	2,895,621	667,335	2,228,286
2017	2,999,039	688,779	2,310,260
2018	3,066,350	653,764	2,412,586
2019	3,038,352	657,258	2,381,094

Total work hours showed an increasing trend from 1997 and peaked in 2014.

Table B11: Exposure hours by region (2018 and 2019)

Region	Hours (thousands)	
	2018	2019
Africa	537,130	480,700
Asia / Australasia	531,067	594,527
Europe	250,880	275,861
Middle East	756,946	675,784
North America	367,241	369,476
Russia & Central Asia	220,906	246,248
South & Central America	402,180	395,756
OVERALL	3,066,350	3,038,352

2018-2019 Middle East region has the highest exposure hours for the year range.

Table B12: Exposure hours by function (2018 and 2019)

Function	Hours (thousands)	
	2018	2019
Exploration	31,899	37,879
Drilling	373,205	399,030
Production	1,282,002	1,339,025
Construction	725,186	651,578
Unspecified	654,058	610,840
OVERALL	3,066,350	3,038,352

For the year range, 2018-2019 production function has the highest exposure hours

Annex C Data Collection

Introduction: This survey aims to gather primary data from oil and gas field personnel. Please note that the survey is for academic purposes and is entirely anonymous. Could you choose one from the given questions based on your field experience in oil and gas safety practices? There is no correct and wrong answer, just personal opinion.

Question 1.

In your opinion, who do you think has the **main** responsibility in drafting oil and gas safety systems, procedures, plans, and policies?

- A. Top management B. safety officer C. frontline employees D. regulatory bodies

Question 2.

In your opinion, what could be the **main** cause of accidents in the oil and gas upstream offshore sector?

- A. Employees B. broken processes C. unsafe conditions

Question 3.

In your opinion, what is the **common** injury type in the oil and gas upstream offshore sector?

- A. Hand injury B. Back injury C. eye injury D. Neck injury

Question 4.

In your opinion, what is the leading indicator for predictive safety measures for the oil and gas upstream offshore sector?

- A. fatality B. recordable injuries C. near misses D. lost-time days

Table C1: Injuries on permanently placed facilities.

Activity		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Administration and production	Work-hours	8 920 468	8 975 538	8 715 265	8 997 539	9 386 604	10 084 881	8 869 938	7 744 388	8 329 241	10 699 902
	Injuries	39	28	22	40	38	25	26	18	33	17
	Injury rate	4,4	3,1	2,5	4,4	4,0	2,5	2,9	2,3	4,0	1,6
Drilling and well operations	Work-hours	6 363 025	5 893 739	5 594 466	5 149 376	5 553 985	5 166 295	4 856 239	4 499 170	4 503 183	4 598 378
	Injuries	48	47	43	40	41	28	32	29	27	21
	Injury rate	7,5	8,0	7,7	7,8	7,4	5,4	6,6	6,4	6,0	4,6
Catering	Work-hours	2 221 184	2 321 410	2 402 714	2 466 948	2 426 849	2 347 674	2 154 055	2 090 811	1 988 017	2 101 929
	Injuries	28	23	24	14	26	12	23	15	19	9
	Injury rate	12,6	9,9	10,0	5,7	10,7	5,1	10,7	7,2	9,6	4,3
Construction and maintenance	Work-hours	11 079 666	11 834 044	14 951 055	15 408 376	15 721 547	15 125 636	10 636 021	9 779 982	9 309 383	10 661 638
	Injuries	133	122	154	157	137	178	113	82	92	103
	Injury rate	12,0	10,3	10,3	10,2	8,7	11,8	10,6	8,4	9,9	9,7
Total	Work-hours	28 584 343	29 024 731	31 663 500	32 022 239	33 088 985	32 724 486	26 516 253	24 114 351	24 129 824	28 061 847
	Injuries	248	220	243	251	242	243	194	144	171	150
	Injury rate	8,7	7,6	7,7	7,8	7,3	7,4	7,3	6,0	7,1	5,3

Table C2 Fatality by activity (2015-2019)

Number of fatalities					
Activity	2015	2016	2017	2018	2019
Construction, commissioning, decommissioning	4	6	2	4	2
Diving, subsea, ROV	2	0	1	1	2
Drilling, workover, well services	12	6	10	12	2
Excavation, trenching, ground disturbance	0	0	0	0	2
Lifting, crane, rigging, deck operations	5	3	3	5	6
Maintenance, inspection, testing	3	6	6	3	4
Office, warehouse, accommodation, catering	1	0	0	0	0
Production operations	14	3	4	1	1
Seismic/survey operations	2	1	0	1	0
Transport - Air	0	19	0	0	0
Transport - Land	7	5	6	3	4
Transport - Water, incl. marine activity	1	1	0	1	2
Unspecified - other	3	0	1	0	0
OVERALL	54	50	33	31	25

As illustrated in Table 7.5, production, drilling, and transportation are the three main activities that caused the highest fatalities, Fatality by activity (2015-2019)

Table C3: Fatalities by cause (2015-2019)

Fatalities by cause (2015-2019)					
Number of fatalities					
Cause	2015	2016	2017	2018	2019
Assault or violent act	1	0	0	0	0
Aviation accident	0	19	0	0	0
Caught in, under or between (excl. dropped objects)	11	6	9	11	12
Confined space	0	2	4	0	0
Cut, puncture, scrape	0	1	0	0	0
Dropped objects	-	-	-	1	1
Explosion	18	9	5	8	0
Exposure electrical	2	0	1	1	4
Exposure noise, chemical, biological, vibration, extreme temperature	1	0	0	0	0
Falls from height	2	2	1	4	2
Overexertion, strain	0	0	0	0	0
Pressure release	5	1	0	0	0
Slips and trips (at same height)	0	0	0	0	0
Struck by (not dropped object)	10	10	12	4	3
Water related, drowning	1	0	0	2	3
Unspecified - Other	3	0	1	0	0
OVERALL	54	50	33	31	25

Note that dropped objects were not a cause category until 2018.

As shown in Table 7.4, Explosion, being caught in between, and being struck by are the three most causes that led to Fatalities (2015-2019)

Table C4 Fatalities, fatal accident rate, fatal incident by regions

Region	Fatalities		Fatal accident rate		Fatal incident	
	2018F	2019F	2018A	2019A	2018I	2019I
Africa	6	6	1.12	1.25	6	5
Asia / Australasia	5	1	0.94	0.17	5	1
Europe	0	2	0.00	0.73	0	2
Middle East	9	4	1.19	0.59	7	3
North America	2	6	0.54	1.62	2	5
Russia & Central Asia	3	1	1.36	0.41	1	1
South & Central America	6	5	1.49	1.26	6	5
OVERALL	31	25	1.01	0.82	27	22

Table C5 Total Recordable injury rate by region

	Total recordable injury rate (TRIR)				
	2015	2016	2017	2018	2019
Africa	0.76	0.50	0.48	0.50	0.42
Asia / Australasia	0.92	0.81	0.75	0.72	0.60
Europe	2.22	2.07	2.07	2.17	2.26
Middle East	0.73	0.48	0.55	0.43	0.44
North America	2.13	1.84	1.96	2.00	1.66
Russia & Central Asia	0.69	0.52	0.44	0.54	0.58
South & Central America	2.08	1.83	1.44	1.64	1.35
OVERALL	1.21	1.03	0.96	0.99	0.92

Table C6 Total Recordable Injury Rate (2010-2019)

Total Recordable Injury Rate					
	Company	Contractor	OVERALL	Onshore	Offshore
2010	1.19	1.81	1.68	1.41	2.45
2011	1.32	1.88	1.76	1.45	2.84
2012	1.12	1.90	1.74	1.49	2.53
2013	0.95	1.77	1.60	1.33	2.34
2014	0.90	1.70	1.54	1.33	2.16
2015	0.89	1.30	1.21	1.08	1.65
2016	0.82	1.09	1.03	0.83	1.60
2017	0.78	1.01	0.96	0.80	1.37
2018	0.72	1.06	0.99	0.88	1.27
2019	0.67	0.98	0.92	0.81	1.20

Table C7: Fatalities and fatal incidents by function (2015-2019)

Table: Fatalities and fatal incidents by function(2015-2019)										
Function	Fatal incidents					Fatalities				
	2015	2016	2017	2018	2019	2015	2016	2017	2018	2019
Exploration	3	1	0	1	0	3	1	0	1	0
Drilling	9	8	14	11	4	10	8	15	12	4
Production	22	14	12	9	13	35	28	14	9	16
Construction	4	4	2	3	3	4	6	2	4	3
Unspecified	2	2	2	3	2	2	7	2	5	2
OVERALL	40	29	30	27	22	54	50	33	31	25

Table C8: Injuries on permanently placed facilities.

Activity		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Administration and production	Work-hours	8 920 468	8 975 538	8 715 265	8 997 539	9 386 604	10 084 881	8 869 938	7 744 388	8 329 241	10 699 902
	Injuries	39	28	22	40	38	25	26	18	33	17
	Injury rate	4,4	3,1	2,5	4,4	4,0	2,5	2,9	2,3	4,0	1,6
Drilling and well operations	Work-hours	6 363 025	5 893 739	5 594 466	5 149 376	5 553 985	5 166 295	4 856 239	4 499 170	4 503 183	4 598 378
	Injuries	48	47	43	40	41	28	32	29	27	21
	Injury rate	7,5	8,0	7,7	7,8	7,4	5,4	6,6	6,4	6,0	4,6
Catering	Work-hours	2 221 184	2 321 410	2 402 714	2 466 948	2 426 849	2 347 674	2 154 055	2 090 811	1 988 017	2 101 929
	Injuries	28	23	24	14	26	12	23	15	19	9
	Injury rate	12,6	9,9	10,0	5,7	10,7	5,1	10,7	7,2	9,6	4,3
Construction and maintenance	Work-hours	11 079 666	11 834 044	14 951 055	15 408 376	15 721 547	15 125 636	10 636 021	9 779 982	9 309 383	10 661 638
	Injuries	133	122	154	157	137	178	113	82	92	103
	Injury rate	12,0	10,3	10,3	10,2	8,7	11,8	10,6	8,4	9,9	9,7
Total	Work-hours	28 584 343	29 024 731	31 663 500	32 022 239	33 088 985	32 724 486	26 516 253	24 114 351	24 129 824	28 061 847
	Injuries	248	220	243	251	242	243	194	144	171	150
	Injury rate	8,7	7,6	7,7	7,8	7,3	7,4	7,3	6,0	7,1	5,3

The secondary data used for model development has been structured as CSV (Comma Separated Values), a simple file format used to store tabular data, such as a spreadsheet or database. CSV file stores tabular data (numbers and text) in plain text.

Table C9 CSV file for python data frame

Year	Activity	Work-Hours	Injuries	Injury-rate
2009	Administration and production	8920468	39	4.4
2009	Drilling and well operations	6363025	48	7.5
2009	Catering	2221184	28	12.6
2009	Construction and maintenance	11079666	133	12
2010	Administration and production	8975538	28	3.1
2010	Drilling and well operations	5893739	47	8
2010	Catering	2321410	23	9.9
2010	Construction and maintenance	11834044	122	10.3
2011	Administration and production	8715265	22	2.5
2011	Drilling and well operations	5594466	43	7.7
2011	Catering	2402714	24	10
2011	Construction and maintenance	14951055	154	10.3
2012	Administration and production	8997539	40	4.4
2012	Drilling and well operations	5149376	40	7.8
2012	Catering	2466948	14	5.7
2012	Construction and maintenance	15408376	157	10.2
2013	Administration and production	9386604	38	4
2013	Drilling and well operations	5553985	41	7.4
2013	Catering	2426849	26	10.7
2013	Construction and maintenance	15721547	137	8.7
2014	Administration and production	10084881	25	2.5
2014	Drilling and well operations	5166295	28	5.4
2014	Catering	2347674	12	5.1
2014	Construction and maintenance	15125636	178	11.8
2015	Administration and production	8869938	26	2.9
2015	Drilling and well operations	4856239	32	6.6
2015	Catering	2154055	23	10.7
2015	Construction and maintenance	10636021	113	10.6
2016	Administration and production	7744388	18	2.3
2016	Drilling and well operations	4499170	29	6.4
2016	Catering	2090811	15	7.2
2016	Construction and maintenance	9779982	82	8.4
2017	Administration and production	8329241	33	4
2017	Drilling and well operations	4503183	27	6
2017	Catering	1988017	19	9.6
2017	Construction and maintenance	9309383	92	9.9
2018	Administration and production	10699902	17	1.6
2018	Drilling and well operations	4598378	21	4.6
2018	Catering	2101929	9	4.3
2018	Construction and maintenance	10661638	103	9.7

The Python code for developing the injury prediction is presented below.

```
# -*- coding: utf-8 -*-  
  
"""  
  
@author: Desalegn  
  
"""  
  
import pandas as pd  
  
import numpy as np  
  
import matplotlib.pyplot as plt  
  
from sklearn.preprocessing import OneHotEncoder  
  
from sklearn.model_selection import train_test_split  
  
from sklearn.model_selection import GridSearchCV  
  
from sklearn.ensemble import RandomForestRegressor  
  
from sklearn.metrics import r2_score  
  
#import data  
  
df = pd.read_csv('Data-1.csv')  
  
#%% One Hot Enconding  
  
#import encoder  
  
cat_enc = OneHotEncoder(handle_unknown='ignore')  
  
#encode Activity column  
  
enc_df = pd.DataFrame(cat_enc.fit_transform(df[['Activity']]).toarray())
```

```

##### Merging data frames df + enc_df

reduced_df = df.drop(['Activity'], axis=1) #create a new data frame dropping the activity
column as it is hot encoded

final_df = enc_df.join(reduced_df).to_numpy() # merge both dataframes

##### Data Preparation for ML

X = final_df[0:,:7] #Features: Year, Activity, Work-Hours, Injuries

y = final_df[0:,-1] #Labels: Injury-rate

#Create train and test dataset with an 80:20 split

x_train, x_test, y_train, y_test = train_test_split(X,y,test_size=0.2,random_state = 0,shuffle
= False)

#Further divide training dataset into train and validation dataset with an 80:20 split

x_train, x_val, y_train, y_val = train_test_split(x_train,y_train,test_size=0.2,random_state
= 0, shuffle = False)

##### Hyperparameter tuning

#Random Forest

param_list1 = {"n_estimators": [10,30,50,70], "max_depth": [10,20,30]}

RFR_model = RandomForestRegressor(random_state = 0)

grid_search1 = GridSearchCV(RFR_model, param_grid=param_list1 , cv=10, scoring='r2'
, n_jobs=4).fit(x_train,y_train)

print("Best parameters RandomForest:", grid_search1.best_estimator_)

print("Best score RFR:", grid_search1.best_score_)

##### Function for running ML models

def evaluate_model(rf, x_train, x_val, x_test, y_train, y_val, y_test):

```

```

rf.fit(x_train, y_train)

validation = rf.predict(x_val)

predictions = rf.predict(x_test)

print(f'R2_val = {r2_score(y_val,validation)}')

print(f'R2 = {r2_score(y_test,predictions)}')

plt.figure(figsize=(6,6))

# function to plot results

plt.scatter(y_test,predictions, s=2, c="black",label="Data sample", alpha=1)

plt.plot([0,np.max([y_test,predictions])],[0,np.max([y_test,predictions])],c="red",
linewidth=1, linestyle="-.", label="perfect prediction")

plt.xlabel("Truth")

plt.ylabel("Model")

plt.legend()

plt.grid()

plt.text(0.061, 0.001, f'$R^2$ = {np.round(r2_score(y_test,predictions),3)}')

return

#%% Random Forest

rf = RandomForestRegressor(n_estimators = 30, random_state = 0,max_depth=10)

evaluate_model(rf, x_train, x_val, x_test, y_train, y_val, y_test)

#%% Random Forest

```