UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO

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Importance of Integrating Human Factors Engineering in the Oil Industry

TESIS

Que para obtener el título de

Ingeniero Petrolero

P R E S E N T A

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Abstract

Human Factors Engineering (HFE) plays a pivotal role in enhancing safety, efficiency, and overall performance within complex industrial settings. The oil industry, renowned for its intricate and high-risk processes, necessitates a comprehensive understanding of Human Factors (HF) to ensure a resilient and safe working environment, at the same time it becomes economically profitable.

The study investigates the integration of HFE methodologies to identify, analyze, and address human-related challenges within petroleum projects. It provides an overview of the application of HFE principles in the oil industry, emphasizing its significance in mitigating risks and optimizing operations.

Key aspects of this exploration include the influence of human performance, organizational dynamics, project implementation, and cognitive aspects. Strategies for mitigating these factors are explored to improve safety and operational feasibility considering human failure as a symptom of an important issue within the organization since this discipline incorporates every aspect of the work environment and human performance as a single matter.

The idea is supported by comparing well-known accidents within the oil industry: Piper Alpha, Deepwater Horizon, and Ixtoc-1, which were caused by the problems that HFE pretends to solve. The experience acquired from these events represents a milestone for HF worldwide. Countries such as the US, UK, Norway, etc. have reported improvement in their practices due to the application of this knowledge. For that reason, the research also aims to introduce this field of study in the Mexican context highlighting potential areas for improvement in HFE implementation to provide an international example of how to contribute with valuable insights to industry regulators and researchers, fostering a safer and more efficient working environment within the global oil sector.

In conclusion, this analysis outlines the importance of Human Factors Engineering as a crucial component in the oil industry's pursuit of operational excellence and safety. By recognizing and addressing the human element, this research aspires to propel the industry toward a future characterized by enhanced reliability, reduced incidents, and improved overall performance.

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1. Introduction:

Mexico is the 16th largest energy consumer worldwide and is the 12th nation in oil production. Its importance has been increasing since the 20th century when it became an exporter country. Nowadays, Mexican oil production represents 2.15% globally (BP, 2023), similar in proportion to Norway or Kuwait. Petróleos Mexicanos (PEMEX), the national oil company, has presented more than 200 investment projects in 2023, whose are centered in the Ku-Maloob-Zaap project, which is located in Campeche and Tabasco and includes the Ku, Maloob, Zaap, Bacab, Lum, Ayatsil, Tekel and Pit fields. Additionally includes pressure maintenance, infrastructure development, and extra-heavy oil processing.

In terms of safety, the figures of Petróleos Mexicanos have increased by 40%, which is translated into more than 0.1 accidents per million man-hours exposed to risk in 2017, Fig. 1, which demonstrates that the results in safety have moved away from international standards.

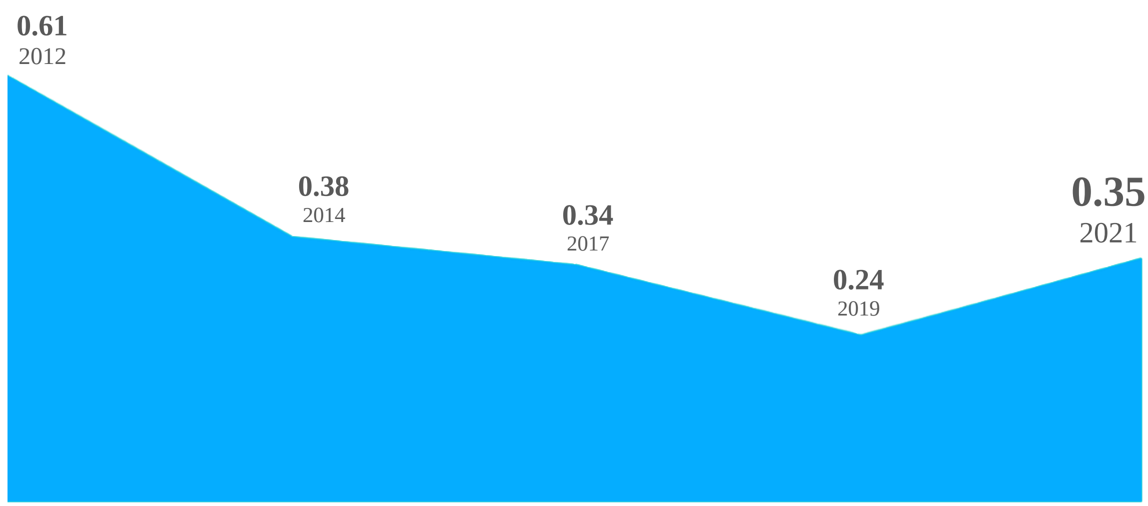

Figure 1. ***Accidents per million man-hours in hazardous activities in PEMEX.***

According to the last PEMEX Sustainability Report, for 2021, the accumulated frequency rate for personnel had a value of 0.35 accidents per million man-hours worked with hazard exposure, which figure is 46% higher than that recorded last year, and 52% higher than the goal of 0.23 established for this period. This index is 59% higher than the international standard of 0.22, which was established by the IOGP for 2021. Regarding the breakdown by each business line, the highest frequency index belongs to *PEMEX Transformación Industrial* (PEMEX Industrial Transformation, followed by *PEMEX Logística* (PEMEX Logistics), and *PEMEX Exploración y Producción* (PEMEX Exploration and Production), according to the national oil company.

Although serious accidents in the industry occur infrequently, they cause severe consequences, and this is due to the different risks inherent to the hydrocarbon sector. Such as the semisubmersible rig Deepwater Horizon that exploded in April 2010, clamming the lives of 11 workers, causing the entire loss of the platform and the largest oil spill in the history of the United States. Also, the event occurred on the coast of Aberdeen, Scotland in 1988; the Piper Alpha platform was destroyed, and 167 of 226 people died due to a series of catastrophic explosions. Failures as simple but important, just as a poor implementation of alarm systems and improper design of a system interface, allowed these events to occur. Likewise, in both examples, the lack of risk perception, poor emergency response training, and insufficient safety culture were highly involved.

In recent years, a significant number of studies have been conducted to uncover the factors that impact human behavior and performance within the workplace. These factors include diverse issues, such as workspace design, the selection of personnel to perform specific jobs, how procedures are written and/or illustrated, operating and maintenance procedures, how policies are presented to employees, the influence of the work environment on the worker performance and how it affects the daily changes in the life of an individual, all of this to reduce the probability of human errors occur and, if necessary, minimize the effects of these events.

This body of knowledge about human behavior and performance in the workplace is known as Human Factors (**HF**) and has given rise to a new profession in the energy sector: Human Factors Engineering (**HFE**). The International Association of Oil and Gas Producers (**IOGP**) provides the following definition of HF and explains the difference between HF and HFE.

> "*In simple terms, human factors are all those things that enhance or improve human performance in the workplace. As a discipline, Human Factors is concerned with understanding interactions between people and other elements of complex systems. Human Factors applies scientific knowledge and principles as well as lessons learned from previous incidents and operational experience to optimize human well-being, overall system performance, and reliability. The discipline contributes to the design and evaluation of organizations, tasks, jobs and equipment, environments, products, and systems. It focuses on the inherent characteristics, needs, abilities, and limitations of people and the development of sustainable and safe working cultures.*
> *Human Factors Engineering focuses on the application of human factors knowledge to the design and construction of socio-technical systems. The objective is to ensure systems are designed in a way that optimizes the human contribution to production and minimizes the potential for design-induced risks to health, personal or process safety, or environmental performance."*
>
> *(McLeod, 2015)*

This definition is important to understand the difference between the concept of HF, which is quite broad, and HFE, which represents a subspace within HF focused on the design of socio-technical systems.

This discipline has gradually been gaining greater importance in recent years, and much has been learned about HFE programs implemented around the world. These experiences have been documented for research purposes, both academia and industry have detected even more considerations between human errors and industrial accidents since the identification of errors has continually been the cause of accidents in the absence of properly designed systems. Fig.2 shows the growing number of publications after 2014. Such movement has been mainly driven by the IOGP and the Society of Petroleum Engineers (**SPE**). Previous perspectives supported the idea that systems considered people's inherent unreliability as the primary threat to safety. Nowadays, human error is not considered a cause, but rather the symptom of a problem in the design of any large-scale system. This promotes the fact that human errors can be systematically addressed through the characteristics associated with people, tools, jobs, and the work environment. Consequently, the resulting process in safety comes from a better understanding and influence of the aforementioned conditions.

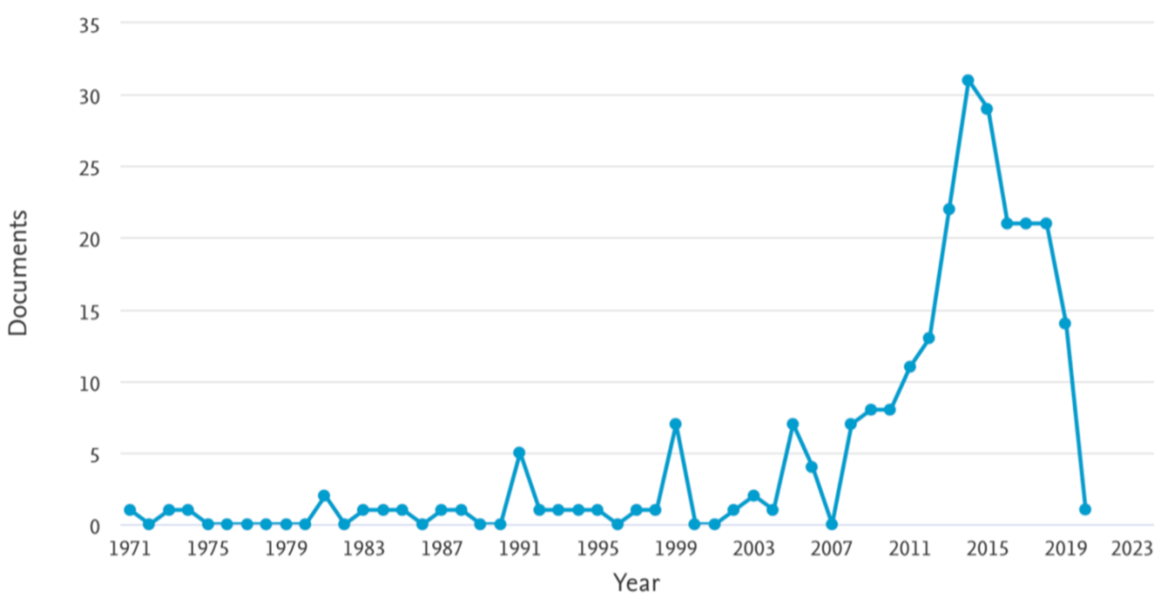

Figure 2. ***Documents by year of Human Factors and deepwater or drilling. (Bruno, 2020)***

2. HFE in the Oil Industry

2.1. History of HFE

The beginnings of the study of human performance date back to 1898, Frederick W. Taylor (Fig.3), a mechanical engineer, considered the father of scientific management, modified the way workers performed their tasks at the *Bethlehem Steel Company*, providing them with customized tools and modifying personnel selection, HF training, and work-rest schedules through data gathering and statistical analysis. All of these modifications resulted in a threefold production increase.

Figure 3. ***Frederick W. Taylor***

In the first years of the 20th century, psychology grew dynamically as a discipline in different industries. Flying aptitude testing was first conducted for the US Army, focusing on improving pilot selection and training. Subsequently, the scope moved from pilots to aircraft design, examining the impact that controls, displays and the gravity force had on the decision-making and behavior of the soldiers. As a consequence of having researched about the limits of human and mechanical performance, it was possible to develop the first G-suit in 1937 to deal with the increased force of gravity (Fig. 4). This suit was designed to prevent loss of consciousness caused by blood pooling in the lower part of the body when accelerating, depriving the brain of blood, a situation that has caused several fatal plane crashes.

Figure 4. ***First G-suit Used in Real-Life Combat, during the Invasion of North Africa in 1942.***

World War II accelerated psychological research into high-risk activities, allowing better designs to be created by understanding the physical and mental needs of users, e.g. radar controls and displays allowed more effective recognition of enemy aircrafts. These studies laid the foundations for the HFE by targeting:

- System performance.
- Problems in the presence, detection, and recognition of information.
- Action controls.
- Workplace.

Solving such challenges required engineers to work closely with psychologists, and although the military sponsored almost all HFE research during the war, the civil industry was also interested in generating developments in this area because of the added value it provided. During this time, many other industries began to realize that the greatest effectiveness in achieving desired objectives does not depend solely on humans or technology, rather, it depends on how well people, machines, and processes interact to create a system. This requires a multidisciplinary approach involving psychology, physiology, engineering, computer science, statistics, and many others.

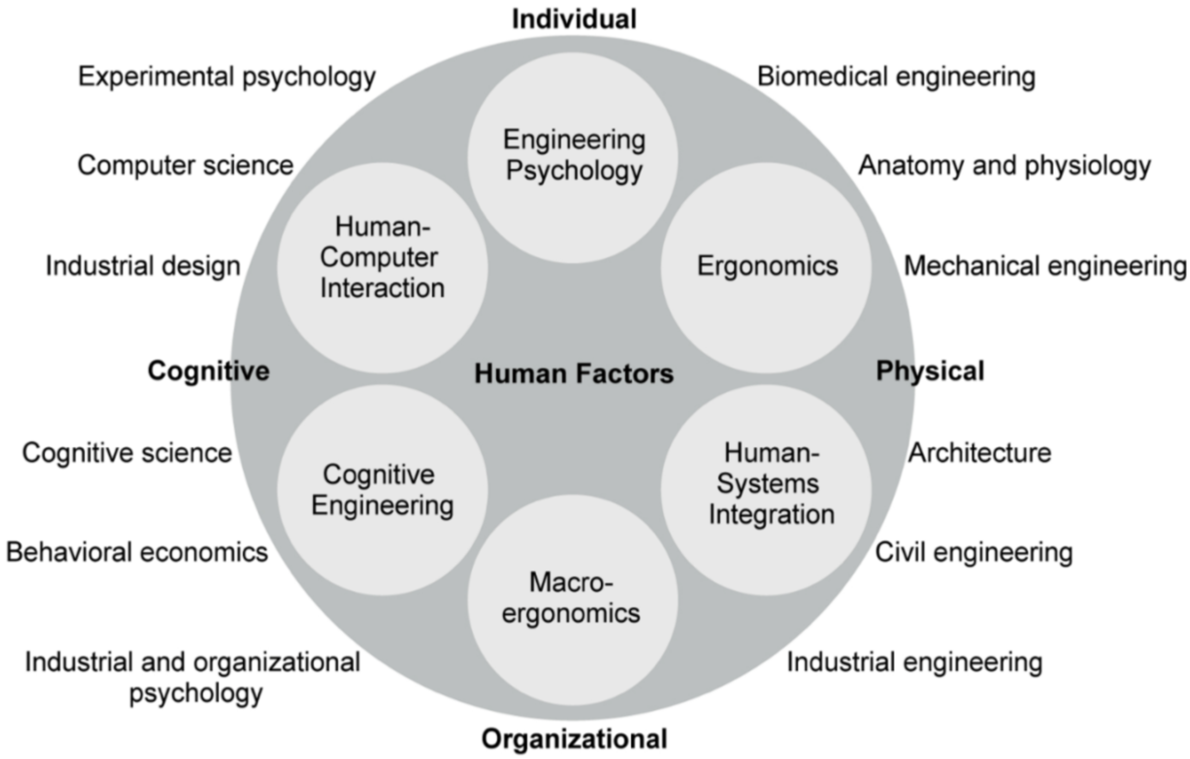

Figure 5. ***Domains of Human Factors. (J. D. Lee, 2017)***

Another way to view the scope of HF is to consider its relationship to the domains of science and engineering, as shown in Figure 5. Moving from the top to the lower part, the diagram involves a change in emphasis from the individual to an organization. From the left side to the right implies a shift in the scope, ranging from cognitive to physical considerations. The six closely related disciplines are shown as circles within the broad range of HF. Finally, outside the circle, there are represented other disciplines that are likely to overlap with some aspects of human factors. These efforts led to the establishment of bodies for HFE professionals, such as the Chartered Institute of Ergonomics and Human Factors in the United Kingdom in 1949 and the Ergonomics and Human Factors Society in the United States in 1957.

HFE has been used for nearly eighty years (78) to eliminate human-induced errors in the workplace, but its use has continually expanded over the past decades. Global examples of success within the energy, manufacturing, aerospace, and military industries have clearly demonstrated that HFE can profitably contribute to reducing human error and increasing employee productivity.

Since it is a profession specialized in working with human capabilities and limitations (physical, social, and psychological) to build an environment that optimizes the contribution of human beings to safety within the workplace. Some companies have begun to use HFE to design, manage, and operate their facilities by implementing solutions that, until recently, have been primarily focused on increased training, improved processes, and/or safety initiatives based on employee behavior to create a safer work attitude. It is easy to understand that all of them are necessary, also that properly designed procedures make the job simpler and avoid complications. However, none of these strategies, alone or together, is the solution to reducing human-caused accidents and incidents.

There is still a question as to whether “human error” is the primary cause or contributor to the vast majority of accidents and incidents in the industry. The oil industry must focus its efforts in this area to prevent accidents. Nevertheless, it is essential to recognize that providing additional training, procedures or behavior-based programs is not the final answer, but rather represents part of the real solution.

2.2. Experience in the industry

In all the processes involved in Exploration and Production (**E&P**), more than in any other sector of the oil industry, the activities involve a higher dependence on the abilities and judgment of individuals and teams to conduct safety-critical responsibilities effectively. Rigorously, the aim is to ensure that employees can perform the duties assigned to them, but it is also imperative to ensure that the environment in which people work maximizes their ability to operate safely and efficiently, by designing the equipment, tasks, and processes so that they are safe even if someone makes a mistake.

In the HF equation, other aspects contribute to safer work, although they are often not reported or addressed. In particular, few people in management or regulatory agency positions seem to be aware of the human needs and basic performance requirements (e.g.: risk homeostasis, spatial relationships, cultural elements, etc.) that all workers have, which must be accomplished by proper workplace design for the employees to achieve their maximum performance and safety potential. Failure to meet these standards could induce or encourage even the most safety-aware and well-trained person to engage in risky behavior, especially in stressful situations.

Managers and regulators must be aware of the importance that their daily decisions can have (such as the acquisition of new equipment, practices that promote rewards or sanctions towards employees, the duration of working shifts, and the organization of the company) to determine how safe workers will be. Even fewer people seem to understand the importance of selecting the right personnel to reduce the likelihood of human error on the job. Only those with specific physical, psychological, and social abilities should be assigned to perform tasks that require those specific characteristics.

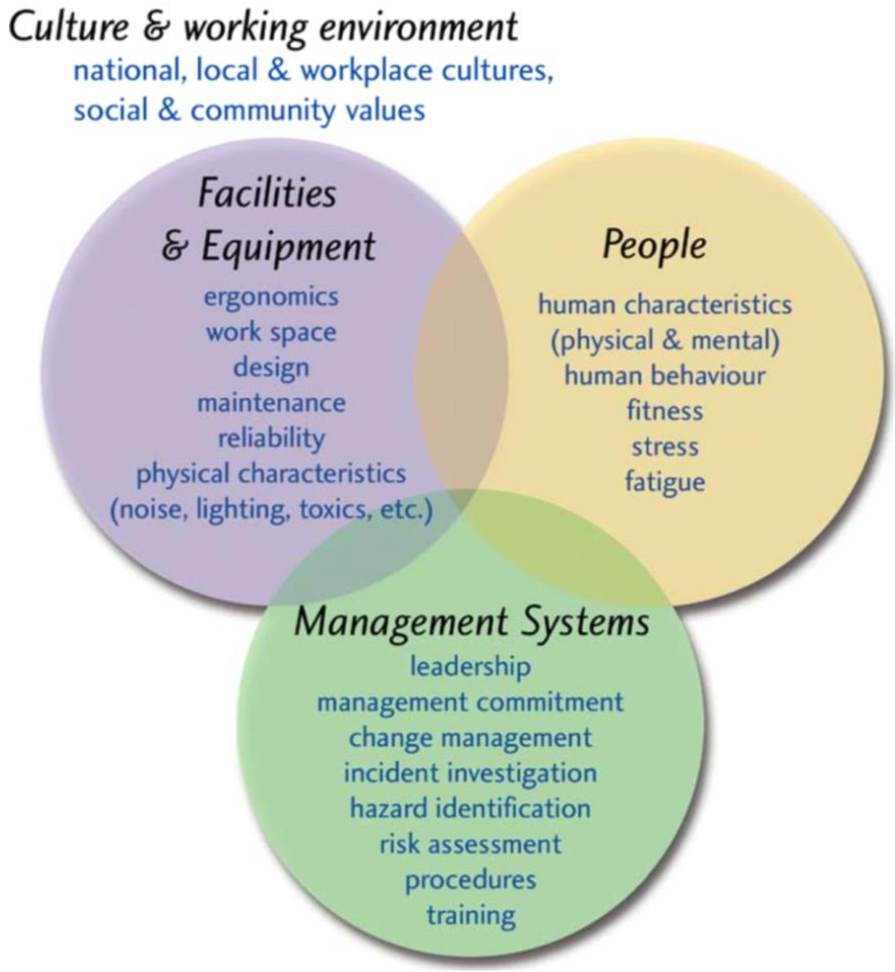

Figure 6. ***Realm of HFE. (IOGP, 2000)***

The three areas described in Figure 6. are:

- People: The characteristics, capabilities, expectations, limitations, experiences and needs of the people who will operate, maintain, support, and use the facilities.
- Management Systems: How the people are organised, in terms of, for example, team structures, responsibilities, working hours and shift schedules
- Facilities and Equipment: The devices and technology used, including the way equipment is laid out, and the elements that people need to interact with, both physically and mentally.

Operations throughout the well life cycle, from drilling to decommissioning, expose personnel to new and changing hazards that must be addressed quickly with a time-constrained analysis and decision-making process. People may find themselves in circumstances where they must make these decisions under stressful and adverse conditions to avoid or mitigate the repercussions of a major accident. To be effective, each operation must be designed in the simplest way possible so that people carry out their established tasks since the procedures, systems, and hardware they rely on are not necessarily adapted to the dynamics of different types of well operations.

Being aware of HF aids in the tuning of activities, systems, and processes to be more useful in the hands of those who need to use them. Furthermore, well operations are carried out under very diverse working conditions; For example, when the site or client changes, the personnel and organization required to carry out any activity may also change. However, the consequences of a failure are so serious that it is necessary to ensure that all these aspects work perfectly together from the beginning of the operation if the risk of a well control event is to be avoided, or to manage its consequences.

While many industries have increased safety and efficiency by strengthening technological and engineering controls and mitigations, there is no denying that humans play an important role in making these operations safe and successful. Today, only a small number of large E&P companies use HFE professionals in the design and management of their projects. However, the application of this knowledge throughout the industry from the design and operation of facilities has been minimal at best, or nonexistent at worst. Meanwhile, other equally sophisticated sectors that are growing have recognized that technical and procedural controls are only effective when they are developed thinking about human beings, this includes taking into consideration the nature of human variability.

By applying Human Factors, the aim is to understand how people interact with the equipment, systems, tasks they must perform, and the relationship they have with their colleagues. Fundamentally, behavior is influenced by a variety of circumstances, such as fatigue, time constraints, daylight (Fig. 7), sleep quality, interruptions, and poor planning.

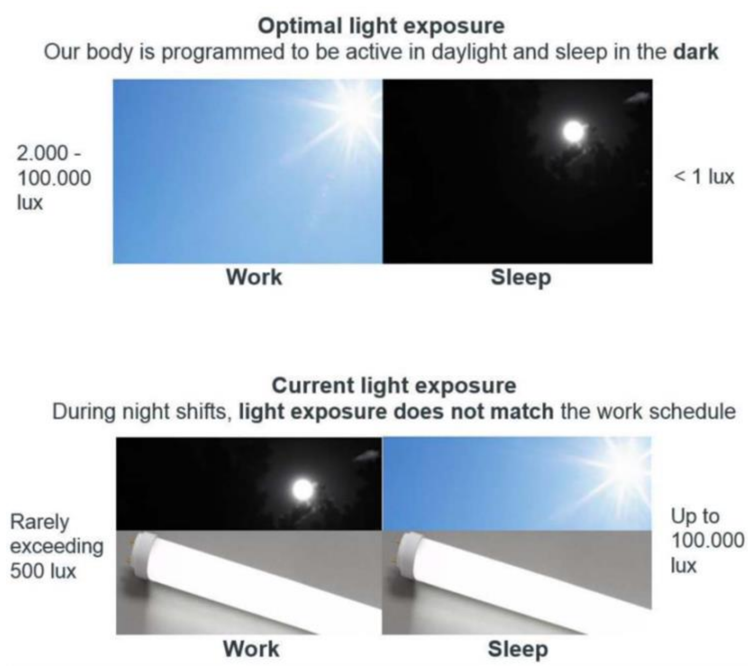

Figure 7. ***Example of the current light exposure when working night shifts. (Meijer et al., 2017)***

Nonetheless, people adapt and commonly work intending to do a good job, if they work under a bad design, have poor shift organization, production demands, and/or other problems in executing their tasks, they will most likely have problems at some point. That's why collaborating with people who understand the workflow and identify what the difficult aspects are can help reduce human error, but working with an HF professional can simplify it even further.

HFE gained strength as a discipline due to the catastrophes in which the industry has been involved. The magnitude and complexity of these accidents caused different researchers to realize the important role of the HF; hence, the need to understand them better and find explanations for human error in these types of accidents. This discussion combined different study disciplines such as sociology, cognitive psychology, human physiology, ergonomics, engineering, and even management sciences. At the same time, these studies created controversies and misconceptions regarding human error throughout the last century. This led to the existence of two opposing perspectives on HF, which define how the role of humans in safety should be understood and how they currently contribute to accidents.

2.3. The Old View

This traditional approach basically describes human error as the main cause of failures. "Unsafe behavior" is due to the erratic nature of people, which compromises a "safe system". In other words, human behavior is a problem that must be controlled.

> "*Failures are unpleasant surprises. They are unexpected and not part of the system. Failures are introduced into the system through the inherent unreliability of people.*"
>
> *(Dekker, 2014)*

The old perspective comprises a Taylorian approach in which workers must be supervised at all times, to ensure that they do what they are assigned to do as safely as possible. In this approach, autonomy and own initiative are not only undesirable but also strongly avoided to protect the systems. Thus, any modification is considered a violation of the established procedures and rules, even when it is not possible to follow the rules to carry out a job. These "violations" are frequently subject to disciplinary action, since safety is measured concerning the number of adverse results in a certain time. This means that the lower the number of incidents, near misses, and/or accidents, the safer the system will be. That is why security management focuses on preventing possible deviations that could end up causing things to go wrong (the safety management paradigm).

Domino Effect

One of the authors who contributed most to the development of the Old View was Herbert William Heinrich; Through his research Industrial Accident Prevention: A Scientific Approach he created one of the most accepted paradigms in safety sciences: *The Domino Effect* or *Domino Model* of accident causes. It explains an accident as the consequence of a chain of events, such as a row of dominoes.

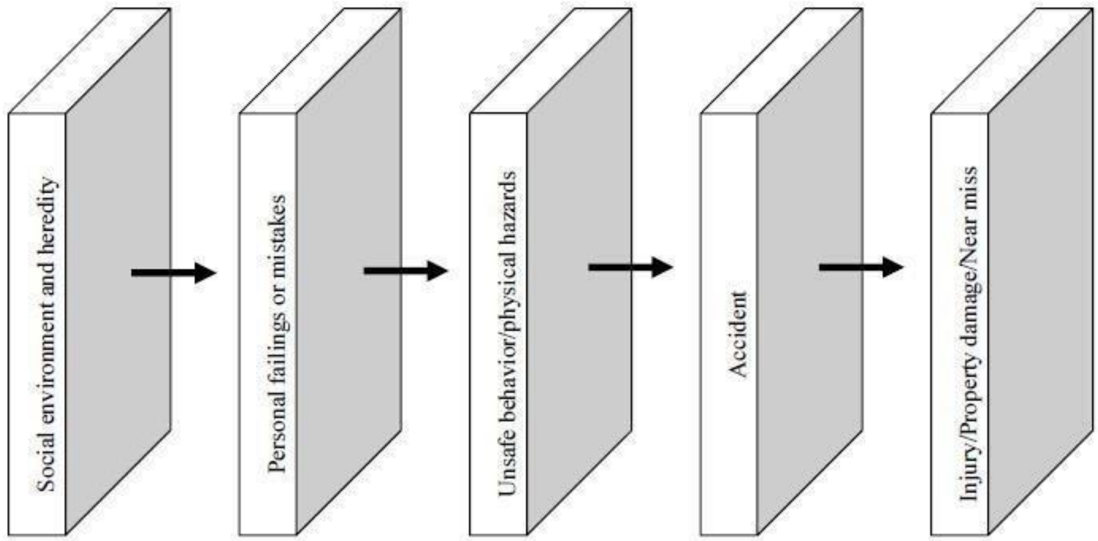

Figure 8. ***Domino Effect, H.W. (Heinrich, 1931)***

In his pyramid, Fig.9, Heinrich also concluded that accidents in the workplace occur due to unsafe acts of people 90% of the time (300/330). Additionally, his accident triangle postulates that there is a mathematical relationship between unsafe acts, minor injuries, and fatalities. This diagram has been one of the strategies in most safety interventions in organizations during the last century, firmly believing that it is the best method to prevent major accidents. However, from minor to major incidents, this approach does not take into consideration adverse effects. Still, it has been adopted by many industries around the world.

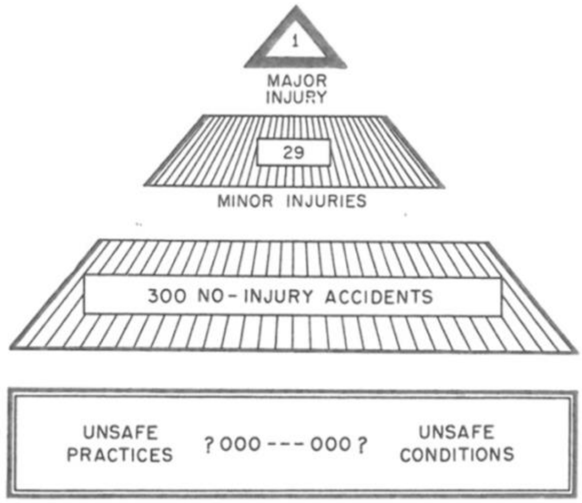

Figure 9. ***Accident Triangle, H.W. (Heinrich, 1931)***

This analysis also considers that accidents are related to people's inattention and carelessness (Burnham, 2009), reinforcing the premise that people are a problem that must be controlled. All of these ideas were fundamental to the development of behavioral theories, which dominated since the 1930s with the publication of the Accident Triangle. These theories have the main objective of influencing or modifying human behavior to address the limitations of work systems, thus laying the foundation for what is known today as behavior-based safety programs (Dekker, 2014).

Swiss Cheese Model

James Reason proposed the *Swiss Cheese* diagram to explain how failures occur. According to this proposal, hazards are prevented through a series of layers to avoid human loss, each with its own weaknesses represented by holes in the diagram, which vary in size and position, but when all the holes are aligned in the barriers, this symbolizes that the danger has become harmful.

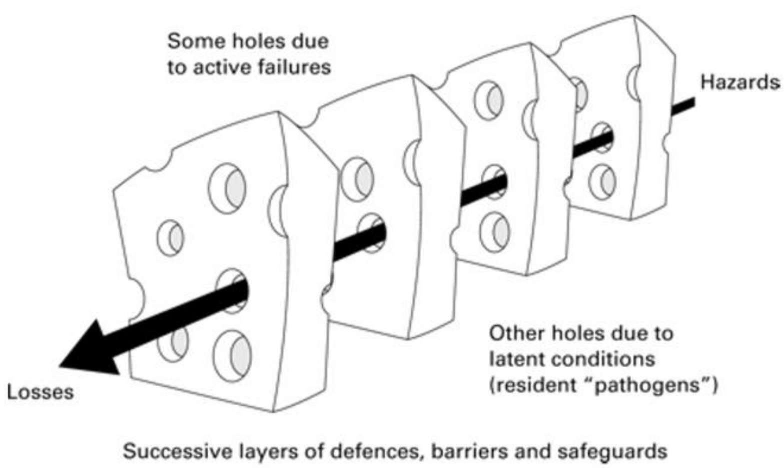

Figure 10. ***Swiss Cheese Model. (J. Reason, 2000)***

The scheme itself is useful in understanding the complexity of failure and, on the other hand, also in the effort needed to create and maintain a secure system. However, this model has many deficiencies: the barriers are not static or constant, nor independent of each other, since they can interact, cross, or rub against each other.

These insufficiencies of this famous scheme are summarized in the following questions:

- Why do holes exist?
- What do the holes consist of?
- Why do holes change with respect to time, size, and location?
- How do the holes line up to cause an accident?

2.4. The New View

The evolution of all sciences in recent years has resulted in a new perspective towards safety and HFE, this new adaptation evolved from the reinvention of HF in the 1940s, where the technological advances of World War II led to create an approach towards systematic thinking driven by research into human errors that began in the late 1970s. Thus, errors caused by people were no longer seen as the cause of a problem, rather they were seen as the symptoms of a deficient system.

> *Human error is the symptom of a problem deep within the system. Safety is not inherent to systems. People must create security. The systems themselves represent contradictions between the multiple objectives that people must meet simultaneously.*
>
> *(Dekker, 2014)*

This new perspective assumes that people do not intend to carry out their activities in a bad way, so errors are not the result of human moral failures. Rather, people create security by learning and adapting to contribute to both successes and failures; Thus, progress is generated by helping workers create safety through their adequate preparation and not by controlling people, since both safety and accidents are dynamic and emergent properties coming from complex interactions within a system.

Even with the traditional implementation of Health, Safety and Environmental (**HSE**) management systems, the industry continues to look for ways to improve its performance. The detailed analysis of the Performance Shaping Factors (**PSF**) becomes essential to complete this search, which includes all the characteristics of the job, the individual and the organization that influence human performance. Among the factors related to jobs that people perform include: the time available or the design of the control panel, as for personal factors there are: fatigue, load capacity and, finally, some of the organizational factors are: the specific roles and positions that each individual occupies.

With a wide range of abilities and limitations, HFE works on how to make the best use of these human capabilities, designing processes and equipment that are right for people. This not only improves your health and safety, but often ensures a better-managed and more effective organization.

Some companies have implemented technologies from other industries to increase efficiency and productivity while decreasing errors in the workplace. One of the most important aspects is having a strong safety culture, which can be defined as all the values and beliefs that interact within the structure of an organization, and with safety controls to create behavioral rules. However, to create and maintain this culture, it is necessary to have strong leadership, because how managers behave and interact with people within the organization, along with the actions and decisions they take to balance security with economic aspects, will determine what the attitude towards safety will be within the organization itself.

The updating of working systems and the improvement of technologies within the industry can favor the fulfillment of these objectives, which are based on having a qualified workforce, correctly designed positions, and appropriate to the capabilities of the employees, otherwise, they would lead to what is known as *error traps*. In HFE, this refers to the mixture of different human failure mechanisms, including forgetfulness, misperception, and accidental or intentional assumption of an incorrect action or decision, combined with poor physical aspects such as equipment, tools, and/or mental ones, such as multitasking, fatigue or ambiguous tasks.

Figure 11. ***Control room design with inadequate (left) and adequate (right) workspace from an ergonomic perspective. (IOGP, 2011)***

The influence of biological, psychological, and organizational factors on an individual within their work can affect their health and safety but also affects their efficiency and productivity (Fig. 11). For example, if:

- Someone needs to use a large proportion of their strength to complete a task: they are more likely to suffer injuries and perform the task inefficiently, possibly causing damage to both the person and the tools.
- The mental demand of a task is too high: when working under pressure in stressful environments and with limited time, then there may be a health problem for the employee but also a quality, and possibly, safety problem for the production line, the process, and the plant.
- People have very limited scope to determine how to do their work: They could lack motivation, and job satisfaction, consequently, being less effective at work.

These are all safety-critical aspects of human performance and process safety, should therefore be prevented at all times.

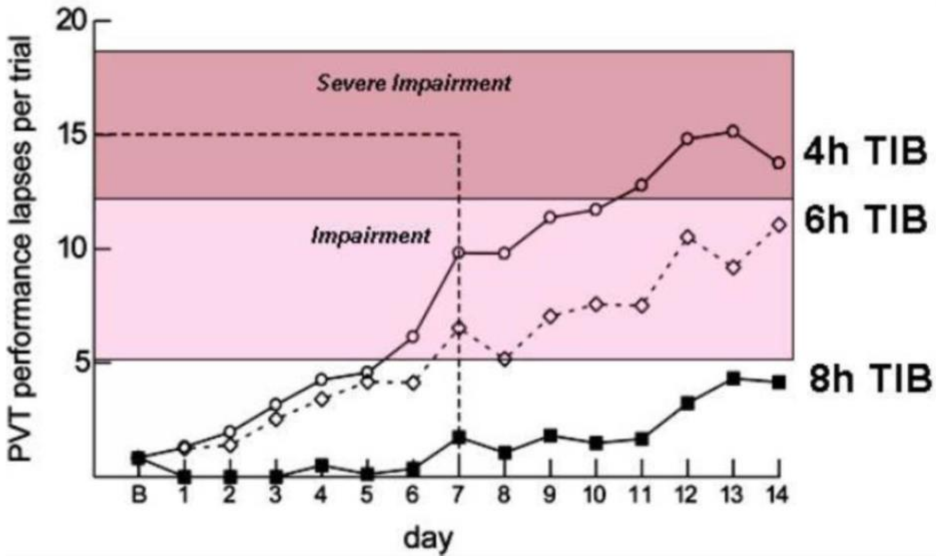

Figure 12. ***A study performed by Van Dongen et al., (2003), showing the effects of accumulated partial sleep deprivation over the course of 14 days. (Meijer et al., 2017)***

When individuals working in shifts cannot consistently achieve the necessary hours of sleep following their shift, a persistent sleep deficit starts to build up. With each instance of inadequate sleep, cognitive performance continues to decline. In Figure 12, the different lines represent the time in bed conditions: 14 days with either 4 hours, 6 hours, or 8 hours of Time in Bed (**TIB**) per night. On the vertical axis the mean number of lapses (i.e. errors; reaction times greater than 500 ms) on the psychomotor vigilance task are presented (Meijer et al., 2017). These findings show that a few days of sleep restriction is more than sufficient in reducing performance, a lack of sleep induces adverse changes in our brain and reduces cognitive performance.

3. Benefits of HFE

Appropriate and timely integration of HFE within the design life cycle is essential to promote the importance of HF consideration in any project, this becomes even more important during its early stages. Ensuring that the HFE has the relevant attention translates as the adequate design of a plant, a system, or equipment to adequately support the operator's tasks by considering their capabilities and limitations. This reduces the likelihood of human error and in turn, leads to improved operational efficiency. Key benefits of achieving effective integration of HFE into an operation include:

- **Improved security and risk mitigation:** The pursuit of improved security and risk mitigation involves a user-centered design approach, where interfaces and workflows are tailored to human capabilities to minimize errors and deviations from protocols.

    Task analysis and workflow optimization: Identify potential points of failure, simplifying procedures to reduce cognitive load and enhance user performance in security contexts.

    Effective communication: Through real-time feedback, clear alerts, and actionable system responses align with HFE principles, contributing to a proactive risk mitigation strategy. HFE emphasizes training programs that simulate realistic security scenarios, fostering user familiarity and competence to minimize errors during actual tasks.

  The integration of features like error prevention, recovery options, and continuous improvement aligns with HFE's goal of designing adaptable systems that evolve with user needs, technological advancements, and emerging threats, ultimately increasing the probability of successful completion of safety tasks.

- **Reduced costs:** Adopting a user-centered approach, incorporating early user feedback to identify and address potential issues, minimizing user errors, streamlining training processes, and proactively mitigating risks associated with user interaction (Hendrick, 2008). HFE's iterative design philosophy ensures continuous improvement and adaptation, preventing the need for costly changes or rework later in the development process. Ultimately, by considering human capabilities from the outset, HFE contributes to more efficient and cost-effective system implementations, aligning with the principle of designing for optimal usability and user satisfaction throughout the system's lifecycle.

- **Improved human performance and labor efficiency:** The incorporation of HFE into workplace design and management leads to improved human performance and labor efficiency, resulting in increased production and operational capacity while simultaneously reducing costs related to facility maintenance. By designing ergonomic workspaces, optimizing workflows, and facilitating human-machine collaboration through automation, HFE enhances overall labor productivity. Training programs based on HFE principles ensure a skilled workforce capable of navigating optimized processes, and safety protocols contribute to a secure work environment, minimizing costs associated with injuries. This knowledge applied to equipment design enhances reliability and supports predictive maintenance strategies, reducing downtime and maintenance expenses. Pursuing a culture of continuous improvement, HFE ensures that operational processes evolve to meet changing demands, creating a harmonious synergy between human capabilities, technology, and cost-effective operational excellence.

- **Decrease in health problems:** Applying HFE significantly contributes to a decrease in health problems, encompassing both physical and mental well-being. HFE reduces the risk of physical health issues related to musculoskeletal disorders and stress-related injuries (Carayon, 2012). The emphasis on mental well-being through stress reduction, work-life balance promotion, and employee involvement in decision-making further contributes to a healthier workforce. This approach not only improves overall employee satisfaction but also leads to decreased healthcare costs associated with workplace-related injuries, mental health issues, and turnover (Meijer, 2017). Thus, it promotes environments that prioritize the comprehensive well-being of employees, aligning with the dual goals of operational excellence and workforce health.

- **Better working conditions:** HFE not only enhances operational efficiency and employee health but also results in better working conditions, leading to increased job satisfaction and a significant reduction in absenteeism during shifts (Meijer, 2017). Employee involvement, stress reduction strategies, and comprehensive training further contribute to job satisfaction, empowering employees and reducing the likelihood of absenteeism. HFE's continuous improvement approach ensures that the workplace evolves to meet changing needs, fostering a positive cycle of satisfaction and attendance.

In a diamond diagram (Fig. 13), the shape can change to lengthen or shorten one of the four points, and each of the points represents a basic intervention strategy: 1) personnel selection, 2) training, 3) human–system interface design, and 4) job performance aids. As one of these points gets implemented, the need for the other strategy points diminishes. Thus, if a better design for the human–system interfaces is implemented, the need for additional training or hiring people with a higher skill level diminishes (Hendrick, 2008).

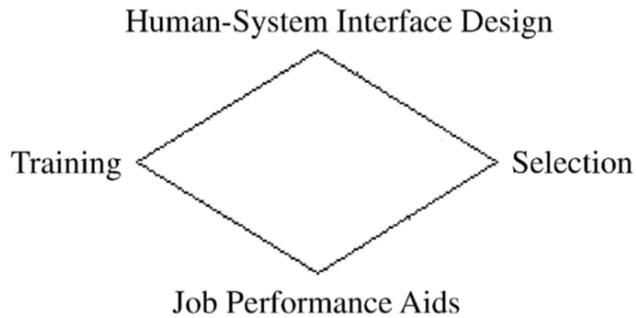

Figure 13. ***The ergonomics trade-off diamond. (Hendrick, 2008)***

3.1. Economic Aspect

As mentioned, the earlier there is HFE participation in the design, the less costly the effort and the greater the benefit. As shown in Table 1, implementation of HFE in a project represents about 1% of the engineering budget when implemented at the beginning. When brought in after the system is put into operation, results in increases greater than 12% (Hendrick, 2008). Van Uden and Rensink in 1999 found that for a typical $400 million petrochemical project, integrating human-centered thinking into a new plant design can result in a 1% savings in engineering hours. However, when justifying the expenditure, it is important to focus on the financial aspect and demonstrate how the project will directly impact the organization's net income.

Stage of development	***Portion of engineering budget (%)***
Early design	1 – 2.5
Blueprint	1 – 3
Construction	2 – 6.5
Commissioning	4 – 10.5
Normal operations	5 – <12

Table 1. ***The costs of using ergonomics in design (Hendrick, 2008)***

To express HFE project proposals in financial terms, it is necessary to conduct a cost-benefit analysis. This involves quantifying both the costs and benefits associated with the project. For costs, there are various factors such as the personnel involved in the project, equipment and materials required, any potential loss of productivity during the implementation, and extra costs attributable to the project. On the other hand, benefits can include personnel savings resulting from improved efficiency and reduced injuries, lower scraps; and increases in output, sales, or company stock value.

In addition to tangible economic benefits, there are also intangible ones that should be acknowledged. While the focus may primarily be on the direct budget impact, it can be mentioned that the project is likely to improve job satisfaction and commitment, which lead to better morale and teamwork, and decreased absenteeism and turnover, but those benefits are insufficient by themselves to ensure a manager to approve the project.

It is crucial to measure the actual costs and benefits of our projects to show the actual value added of HFE and document that valuable information. It is through recent documentation of the value added that this discipline gains/earns credibility with decision-makers, business lines, and other companies, which translates to new opportunities to apply this knowledge.

4. Requirements to apply HFE

There is an increase in regulatory requirements to include IFH in projects for the vast majority of high-risk industries. Within the energy sector, regulators in some countries, including the United Kingdom, Norway, Singapore, and Australia, provide guidance and expected outcomes when integrating HFE within a process. Legislation requiring HFE consideration includes the *Workspace Health and Safety (High Hazard Facilities) Regulations* 2017, created by the Singapore Minister of Manpower, and the Offshore Facilities Regulations. United Kingdom in terms of HSE: *UK HSE Offshore Installations* of 2015, which requires safety case studies for both offshore and onshore platforms in United Kingdom territory, to provide evidence that the risks in safety associated with the HF design have been reduced to lower levels. In addition to regulatory requirements, technical requirements also exist nationally and internationally, even as industrial standards or as specific to a company, e.g. *NORSOK S-002 Working Environment standard*, developed by the Norwegian oil industry.

Requirements in Human Factors Engineering can be a combination of prescriptive, goal-oriented, and procedural requirements (e.g. review of a 3D model, analysis of the requirements for a task, or the critical characteristics of a valve), which may or may not exist simultaneously.

Prescriptive requirements: These are those that specify distances, sizes, spaces, weights, etc., which engineers can apply directly to technical drawings or in calculations (e.g. work area, availability of free space, dimensions of a staircase, etc.). These requirements are met through appropriate reviews, so they must be open to making modifications due to the very nature of humans.

Goal-oriented requirements: These requirements specify the objectives that must be achieved, but not the specific design parameters that must be applied (e.g. support reducing the potential for human error to as low as reasonably possible, support situational awareness, etc.). They can be identified in regulations or standards, or also derived from the specific safety requirements in a project or identified from hazard and operability (**HAZOP**) studies or hazard identification (**HAZID**).

Process requirements: These are those that specify the activities that are expected to be carried out to implement the HFE in a project, the best example is precisely the Human Factors Integration Plan (**HFIP**), whose purpose is to describe in detail how to implement and manage HF considerations in a design, process, or project.

According to the IOGP, the HFIP should do the following:

- Define the roles and responsibilities in the project, including those of other disciplines and any dependencies.
- Define applicable ergonomic standards.
- Define the approaches and methods that will be used in the project, including how the involvement of the end user will be ensured.
- Describe the process that will be used to monitor, manage, and resolve HFE-related problems.
- Describe in detail the activities and work packages that will be carried out, including the required inputs, and resulting products, as well as the acceptance criteria that will be used to qualify the results.
- Demonstrate how IFH activities will be integrated into the entire work program, including deadlines and key points.
- Describe how the PIFH will be maintained and updated.

5. HFE in Mexico

In the case of Mexico, there are some regulation bodies verifying the right designing, proceeding, and emending of its oil industry operations. The first and the most general one is *Secretaría del Trabajo y Prevision Social* – **STPS** (Secretary of Labor and Social Security), which is the agency of the Federal Government that monitors compliance with the labor rights of workers, to guarantee a sustained increase in their quality of life. STPS provides the regulations known as *Norma Oficial Mexicana* – **NOM**-STPS (Mexican Official Standard) with the purpose of establishing the minimum conditions needed to prevent working risks, they are intended for the attendance of risk factors that workers are exposed to. Currently, there are in force 41 NOMs related to safety and health in the workspace, which are further classified into five categories: safety, health, organizational, specific, and product. Its application is mandatory throughout the Mexican territory.

NOM-STPS does not consider HF knowledge as a whole but isolates each of its components (equipment, workspace, psycho-social factors, training, ergonomics). The closest standard to the HFE scope is *NOM-035-STPS-2018: Factores de Riesgo Psicosocial* (Psychosocial Risk Factors), which promotes a favorable organizational environment in the workspace by dealing with those factors that can cause anxiety, sleep-cycle disorders, and severe stress derived from the nature of the job functions, and exposure to severe traumatic events or violent acts at workplace (Angüis, 2023).

The accomplishment of the *NOM-035-STPS* requires workers' participation, assuming the responsibility regarding the development of ideal performance, professional growth, and their own being. Despite the intention of this NOM being acceptable, multifactorial concerns make it difficult to follow, since each person has a different perception, culture, beliefs, religion, or even language, making it harder to coincide in the same interpretation of risk and safety.

There is another regulator within the Mexican oil industry: *Agencia de Seguridad, Energia y Ambiente* – ***ASEA*** (Safety, Energy and Environment Agency). According to its website, ASEA regulates and supervises industrial safety and environmental protection concerning the facilities and activities of the hydrocarbon sector with legal, procedural, and cost certainty. To this end, the agency implements certifications, audits, verifications, and makes inspection and supervision visits. The guiding axis under which the ASEA manages the Risks of the regulated activities of the hydrocarbon sector is known as ***SASISOPA*** - *Sistema de Administración de Seguridad Industrial, Seguridad Operativa y Protección del Medio Ambiente*, or Industrial Safety, Operational Safety and Environmental Protection Management System in English. It is based on international standards such as ISO, its objective is to establish the minimum requirements for the formation, authorization, and implementation of the administration systems of companies that perform activities in the oil sector. By implementing SASISOPA, the aim is to adopt an administration system that benefits the performance of the organization, in its activities and processes, generating added value through risk reduction, legal compliance, responsibility, and competitiveness.

In general, the energy industry in Mexico continues to ignore the contributions that HF can generate to create a safer work environment. Furthermore, those companies that have adopted the HFE have demonstrated that the justifications commonly offered for not applying them are not valid. Nevertheless, due to the complexity and dynamism of the oil sector, there are still regulatory gaps that must be evaluated and addressed by the regulatory entities. HFE implementation into Mexican regulations could help to fill most of those gaps, but it must include the entire approach of this discipline; considering humans, equipment, processes, and systems as a whole thing, not separately as is currently set in the national standards.

6. Lessons Learned

6.1. Piper Alpha, North Sea, July 6th, 1988

Built by McDermott Engineering and operated by Occidental Group, the Piper Alpha platform was located almost 200 km northeast of Aberdeen, Scotland. It had four main operational areas, which were separated by firewalls designed to withstand fire caused by hydrocarbons and were arranged in such a way that the most dangerous operating areas were located away from personnel and command areas. The platform was equipped with pumps to supply seawater to the automatic firefighting system.

Figure 14. ***The smoke reached hundreds of feet above Piper Alpha. (NASA Safety Center, 2023)***

On July 6, 1988, the personnel in charge removed the pressure safety valve (which is used to regulate the pressure in case of over-pressurization) from pump A, one of the two that were responsible for displacing the condensate in pipelines to the coast. In addition, pump A had a routine inspection pending, but it had not been carried out for two weeks, since this maintenance was not completed before the shift change at 6:00 p.m., the worker in charge left the blind flange manually tightened and decided to request a permit specifying that the pump A was not ready to operate, and it should not be activated.

At 9:45 p.m., the next shift crew faced a methane hydrate accumulation that blocked the gas compression system, causing the failure of pump *B*, and due to this, all production at the Piper field was stopped. unless either of the two pumps *A* or *B* were restarted. Thus, the workers reviewed the maintenance records to find out if pump *A* was ready to be activated, however, they did not find the permission for the maintenance routine or the missing safety valve, since the worker who removed the valve put the permit on a box near the valve, as described in the permit application system.

Furthermore, the missing blind flange on the valve was located behind other equipment on a higher level, making the problem even more difficult to visually identify. At 9:55 p.m. the workers activated pump *A* believing it could be used safely, despite this, gas began to leak through the blind flange that was tightened by hand. The alarms were activated and moments later, the gas found an ignition source, creating a strong explosion. The fire spread rapidly, engulfing the firewalls designed to withstand high temperatures and causing a huge column of dense black smoke. Emergency systems were activated to stop the flow of gas, this would have contained the fire by individually isolating the units on the platform if they had operated under ideal design conditions, but the fire spread through a small duct carrying condensate. Occidental did not order production to stop, so operators did not believe they had the authority to stop production on the platform.

Ten minutes after the first explosion, the workers evacuated the control room without having any way to contain the disaster; only the firefighting systems were placed in manual mode, as specified by the protocols established by the platform manager. By then, no orders had been given to evacuate, nor were emergency signals issued. Staff had to gather in fireproof rooms waiting for instructions, as they could not reach the lifeboat stations. At 10:20 p.m. the gas pipeline coming from a nearby platform (called Tartan) exploded, feeding almost 100 $\frac{m^3}{s}$ to Piper Alpha, which immediately caught fire.

Rescue by helicopter was impossible due to fire, smoke, and wind. The personnel began to jump from different levels on the platform more than 50 m high. Tharos, a firefighting vessel, attempted to approach the Piper Alpha and fight the fire at 10:30 p.m. but was restricted because its water cannons were so powerful that they could kill anyone if they received a direct hit, so the vessel had to be retired after another explosion occurred due to a ruptured gas line. This explosion caused the fire to increase, reaching several meters in the air and increasing the temperature to the point that both the steel of the platform and some parts of Tharos, began to melt.

The explosion killed two members of the rescue team along with six survivors of the Piper Alpha who jumped into the sea, while the rest of the crew were cornered in the burning rooms. Despite all this, the management of the Tartan platform gave orders not to stop production due to the consequent expense for Occidental and instead await orders to that effect from Aberdeen.

At 11:20 p.m., most of the facilities were already destroyed and sinking into the sea. Of the 226 personnel on the platform, 165 and 2 people from the rescue team who attended such a shocking event died. As would be expected in a disaster of this magnitude, the investigation identified many causes relating to design, operation, safety culture, emergency response, and poor training.

6.2. Deepwater Horizon, Gulf of Mexico, April 20th, 2010

On April 20, 2010, the Deepwater Horizon platform was finishing a drilling job in the Macondo field, located in the Gulf of Mexico (**GOM**) almost 80 km away from the coast of Louisiana. At that point, the operation was 43 days behind schedule and USD 21 million over budget due to additional fees. At 9:49 p.m., the platform exploded, claiming eleven lives, giving rise to the worst oil spill in the history of the United States and the second largest in the world. Before the accident, the Deepwater Horizon, operated by Transocean and leased to BP, was considered one of the platforms in the BP fleet with the best performance in deep water. In September 2009, it drilled the world record 10,685 m of total depth. Until the day of the accident, there had been no incidents related to non-productive time for 7 years.

Figure 15. ***Deepwater Horizon in flames after the explosion. (US Coast Guard, 2010)***

The platform was in the temporary abandonment stage, in which the well is plugged to seal and secure it in order to remove the Blowout Preventer (**BOP**) and riser, so that the well can be safely abandoned until the next platform arrives to open the well again and thus begin the extraction of reserves. Early on April 20, 2010, cement was pumped into the well. Protocols dictate that the Cement Bond Log (**CBL**), which is an acoustic log used to measure the adhesion of cement to the walls of the well, which indicates whether/if the wellbore is properly sealed. The Schlumberger (now **SLB**) team commissioned to run the CBL was sent back to land, as this log would have cost around $128,000 USD. Presumably, if the Schlumberger crew had been allowed to conduct their test, they might have found that the cement job was improperly set, which would have required it to be redone for safety purposes, it would have also placed greater stress on this project that was already delayed and above budget.

Pressure testing under normal circumstances would be carried out after running the CBL successfully, of course this was not met and was done without the necessary prior step. The positive pressure test was successful, but the negative pressure test detected abnormal values, as it is used to indicate whether the cement layer properly isolated the well from the formation fluids. This created an influx from the formation, which flowed up the wellbore, pushing the dense drilling fluid upward, causing the blowout. When it reached the platform, high-pressure gas began leaking from the mud separator relief vents, triggering multiple alarms as the fluid dispersed. The gas subsequently found an ignition source, causing two explosions at approximately 9:49 p.m., followed by fire that completely engulfed the platform. Simultaneously, several attempts were made to close the well and stop the leak of hydrocarbons using the Emergency Disconnect Sequence (**EDS**) without success. The platform sank into the ocean after burning for 36 hours, by that time eleven people died, while the well continued to flow and pollute the Gulf of Mexico for 87 days.

This event is recognized as one of the most catastrophic in offshore drilling operations, because both the deaths and injuries that could have been avoided, and for the spill of more than 5 MMb of crude oil that covered several kilometers in the sea, which had disastrous consequences in the marine life of the region, for these reasons it is considered the second largest oil spill in the world.

There are many lessons that can be learned when considering the series of events that caused the Deepwater Horizon accident: data interpretation, proper testing, changes in processes and protocols, safety culture and communication, which are turn out to be factors shared with other accidents. Additional training in early detection of flares and interpretation of anomalies in stressful situations may have improved early detection and interpretation of abnormal pressure readings that appeared early in the incident.

According to the US Chemical Safety Board's Volume 3 report, the main problems that contributed to the disaster were: organizational politics, fatigue, distraction, multi-tasking, lack of written work instructions and *confirmation bias*, which is defined as the acceptation and the search of evidence only to confirm what people already believe in. These are some of the points that the HFE deals with.

6.3. Ixtoc-1, Campeche Sound, June 3rd, 1979

On June 3rd, 1979, during drilling operations of the Ixtoc-1 exploratory well located within the Campeche Sound, in the GOM, the drilling crew lost control of the well, causing a huge hydrocarbon spill and an unprecedented fire. With a total of 3.52 MMB of oil spilled into the sea, the Ixtoc-1 case became the third largest in the world, only surpassed by the Deepwater Horizon tragedy in 2010 with 5 MMB. and the Gulf War in January 1991 with nearly 6.2 MMB.

Figure 16. ***Aerial view of Ixtoc-1 well blowout. (2007)***

On December 1st, 1978, began the drilling operations of the Ixtoc-1 by the SEDCO-135 semisubmersible platform leased to PEMEX. The well was located 94 km from Ciudad del Carmen, Campeche, and 965 from southern Texas. Its objective was to determine the existence of hydrocarbons in carbonate formations within the Gulf of Mexico. By drilling this well, it was possible to discover an oil field with a daily potential of approximately 800,000 barrels of oil.

When drilling to a depth of 3,627 m on June 2nd, an important fluid loss was observed after they lost the drilling bit. This situation was controlled, and the pipe was immediately extracted to place a plug as a safety measure. However, when lifting the 200 m of the remaining string, an influx occurred at very high pressure, which found its way to the surface and reached the crown of the mast, finding an ignition source. Given the imminent danger of an explosion, the order was given to evacuate the 63 workers who made up the platform crew. The fire in the derrick started at 2:00 a.m., with personnel already boarding the boats. It was not until this moment that all support units in the area were alerted, they sent firefighting equipment, support vessels, planes, helicopters, and rescue boats.

As soon as the personnel were out of danger, the aid boats proceeded to the fire on the platform, managing to contain it after five hours of intense work. As a result of the fire and the high pressures with which the hydrocarbons were flowing, most of the equipment, the tower, and the pipes collapsed, damaging the wellhead along with the BOP system located on the seabed at a depth of 50.5 m below sea level, consequently, the platform heeled over 25º from its original position.

Three days after the accident occurred, the Azteca self-elevating platform arrived in the area and was positioned 780 m from Ixtoc-1 to drill a relief well with which it was intended to reduce the pressure of the fluids released and thus to be able to drown the damaged well. Days later, the Interocean-2 platform arrived, it was installed 850 m from the exploration well to perform the same work as the Azteca platform. Later, two semi-submersible units arrived to inspect the head and the set of BOPs to determine possible alternatives to control the hydrocarbon spill. Until March 9, 1980, the fire was completely extinguished after injecting brine through the relief wells for several days. Finally, the plugging work was completed on April 5 of the same year.

According to PEMEX reports, during the 280 days that the fire lasted, an approximate volume of 3.52 MMB of crude oil was spilled, of this amount 50% was burned, 28% was dispersed, 16% evaporated, and only 5.4% was collected. The currents carried the oil to the coastal areas of Campeche, Tabasco, Veracruz, Tamaulipas, and some areas of Texas, which were severely contaminated. It is estimated that for emergency response, Mexican oil company used MXN 30 million per day by mobilizing 200 ships, 12 aircraft and 500 men, hiring divers to close the well, without success; used container booms and airplanes to spread a chemical dispersant over the spilled oil in over 2,800 km^2.

A hydrocarbon spill on coastal areas of this kind has catastrophic effects on the environment, causing the death of biodiversity, severe damage to mangroves, contamination of water and soil, considerably affecting the ecological balance, which requires several years to restore. In the case of Ixtoc-1, it is important to remember that, in 1979, PEMEX had little experience in offshore drilling and exploitation.

6.4. Comparative Table

	Piper Alpha	*Deepwater Horizon*	*Ixtoc-1*
Date	July 6th, 1988	April 20th, 2010	June 3rd, 1979
Location	North Sea. Aberdeen, Scotland	GOM. Louisiana, US	GOM. Campeche, Mexico
Operator	Occidental Petroleum	Transocean	SEDCO
Deceases	167	11	0 (Unknown)
Environmental Impact	21 days of fire	5 MMB in 87 days	3.52 MMB in 280 days
Accident	Gas leak explosion	Explosion due to a kick while performing a pressure testing and consequent blowout	Explosion due to a kick while drilling and consequent blowout
Causes	- Lack of maintenance. - Firefighting systems deactivated. - Economic pressure.	- Delay in operations. - Poorly executed cementing operation. - Economic pressure.	- Geological conditions - Improper drillstring design.
Related HF	- Bad communication - Poor safety procedures - Lack of fire response training - Inadequate location of signs and emergency exits	- Stress - Fatigue - Distraction - Multitasking - Lack of outbreak response training - Confirmation bias	- Lack of kick training response - Little safety culture - Inefficient security protocols - Little offshore experience

Table 2. ***Comparison among the events from an HFE perspective.***

As seen in Table 2, all three situations took place on offshore installations, which demonstrates the necessity of operation in this setting calls for advanced technology. This complexity renders the drilling process not fully integrated and controlled, introducing new possibilities for errors. Additionally, offshore drilling constitutes a capital-intensive industry, requiring substantial investments often reaching billions of dollars. This financial burden heightens the pressure for enhanced production and efficiency. Furthermore, the challenging living conditions and the diverse array of expertise and cultures on an offshore oil platform align with the idea of a complex environment. When combined with the inherent uncertainties of drilling, harsh environmental factors, and intricate logistics, these elements collectively contribute significantly to complexity and risks.

Economic pressure played a pivotal role in the incidents described due to the capital-intensive nature of offshore drilling. Operating in such environments demands sophisticated technology, often requiring massive investments, sometimes measured in billions of dollars. The substantial financial commitments create a constant need for efficient operations and increased production to justify and recoup the significant expenditures. This economic pressure can lead to a focus on cost-cutting measures, tight schedules, and an emphasis on maximizing output, potentially compromising safety protocols and increasing the likelihood of incidents.

Issues such as inadequate safety measures, poor response training, bad communication, stress, fatigue, and distraction were the main HF that contributed to accidents in offshore facilities, exemplified by the incidents described. These factors compromise safety protocols, impair decision-making, and increase the likelihood of errors in managing the complexities in operations of this kind. Economic pressures, coupled with the demand for increased production, can lead to a culture prioritizing speed over safety, resulting in tragic consequences. Addressing these issues through comprehensive safety measures, training, communication improvements, and stress management is essential for accident prevention in the industry.

7. Accident Investigation

These incidents changed the perspective of HF and safety in the hydrocarbon sector. They confirm the dependence on humans in all aspects of the project or processes since they are involved in any safety system. They are responsible for designing, operating, and maintaining these systems while doing their tasks, performing reviews, and monitoring to detect and prevent high-risk events. If people do not behave as anticipated, this could have negative effects on outcomes by causing or contributing to incidents. Human performance can directly affect effectiveness when deciding and/or acting, and this is precisely what leads to incidents. The objective of any investigation is to understand the conditions that influenced the event, to modify and prevent them from happening again, as well as any other conditions that could cause similar circumstances.

When carrying out the reports, there are two main protagonists:

- Investigator: The person or group of people that leads or is part of a team that examines the incident to understand its causes and contributing factors

- Client: Who receives the results of the investigation or acts on its findings. This person is likely a manager or leader.

The IOGP, in its report number 621, considers five fundamental stages to properly carry out an incident investigation:

1. **Preparation:**
   The client and investigator work together to agree on the limits of the investigation, the formation of the team, and the logistics of mobilization to the site.
2. **Evidence gathering:**
   Investigators begin to understand the story of the incident and collect diverse and often fragile or fleeting evidence from the human factor.
3. **Analysis:**
   Investigators systematically look for explanations for what happened and match them with evidence.
4. **Findings and recommendations:**
   The investigator describes their findings and works with the client to agree on recommendations that will have a sustainable effect.
5. **Report:**
   The final story, evidence, and recommendations that will be used to take action are written down to be used to act.

8. Conclusions

- Thinking about safety requires an HFE perspective, which involves understanding how humans interact with their environment, equipment, and procedures, so every characteristic is considered simultaneously and not individually as it is in the present. Piper Alpha, Deepwater Horizon, and Ixtoc-1 are real-world examples that resulted in significant environmental and human consequences. In each case, the crucial factors that contributed negatively to those accidents were human-related ones, such as communication breakdowns, decision-making errors, multitasking, and inadequate training.

- Incorporating HFE principles into a project is a strategic investment that avoids additional expenses associated with addressing human-related issues later in the project development process. This proactive approach aims to foresee potential issues related to human interactions with their work environment, addressing them before they become problems, this idea aligns with the notion that a proactive and preventive approach to safety is more cost-effective and beneficial in the long term.

- HFE principles, when applied to workplace design, not only enhance operational efficiency and expenses but also create better working conditions, leading to increased job satisfaction and reduced absenteeism during shifts. By prioritizing ergonomic design, optimizing tasks, and considering environmental factors, HFE fosters a comfortable and efficient work environment. Employee involvement, stress reduction strategies, and comprehensive training contribute to job satisfaction and empowerment, lowering the likelihood of errors to occur. HFE's continuous improvement approach ensures workplace evolution to meet changing needs, establishing a positive cycle of satisfaction and attendance.

- Establishing a standard for HFE in countries that do not have done it yet (such as Mexico) in their regulations ensures consistency across various industries. It provides a framework that businesses and organizations can follow to comply with human-centered design principles, fostering a unified approach to safety and usability. In that sense, many international standards organizations and industries recognize the importance of HFE. Aligning procedures with international HFE standards ensures compatibility with global best practices, facilitating international trade and collaboration. Regulations that include HF principles reflect a commitment to ethical considerations and legal responsibilities, this can contribute to creating a regulatory framework that prioritizes the well-being of employees.

9. Recommendations

Further research in HFE within the oil industry should concentrate on developing innovative strategies for workforce transition and retraining. Investigating the socio-technical aspects of transitioning from traditional oil and gas roles to emerging renewable energy sectors is crucial for successful integration. This involves understanding the skill sets required, designing effective training programs, and addressing psychological factors associated with job shifts. Additionally, research should explore how to optimize collaboration between existing oil industry personnel and professionals from renewable sectors, fostering a culture of adaptability and knowledge transfer. By focusing on the human element, this research can contribute to a smoother and more sustainable transition, ensuring that the expertise of the oil industry workforce aligns with the evolving demands of the broader energy landscape.

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