Cognitive ergonomics in the analysis of work on offshore platforms: “Cognitive Bowtie” application

Ergonomia cognitiva na análise do trabalho em plataformas offshore: "aplicativo" Cognitive Bowtie

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ABSTRACT
Ergonomics is a science that deals with the organization of the working environment aiming man’s safety and health. However, ergonomics concepts in the actual scenario follow, mainly, anthropometric aspects (postures, furniture, equipment, cargo transportation) and environmental conditions (temperature and lightning, for example) and are still weak from the cognitive point of view, which covers mental processes such as perception, memory, and reasoning. These concepts are fundamental, specifically in complex working environments and, therefore, the case chosen in this study was the offshore labor. The risk of serious accidents is inherent for workers in the entire boarding season, and they live their time-off under confinement and isolation conditions, as it is not possible to go home after work or contact family and friends except with the devices available in the unit. This research intention is the adaptation of a tool, the BowTie Analysis technique (BTA), to include human factors and cognitive aspects. Thus, through a low-complexity methodology, this approach could be applied in the oil and gas platforms risk management, filling a gap that still needs to be addressed. To expand the cognitive aspects beyond the control rooms, an important activity that also have man-machine interaction and where many accidents can occur on the platforms was chosen: the cranes operation. It is expected that this example will boost the development, or adaptation, of new tools, to be implemented in oil platforms risk management, aiming for greater safety in the accomplishment of the labor activities, being no longer the worker seen as a “problem” in the complex system, since most causes of accidents are attributed to errors made by workers,
Errors that can and should be studied and absorbed by safety systems, which must be designed and built to predict and act before the most common human failures happen. So, the labor journey of professionals who work in offshore oil units could be more and more healthy and safe, as all life should be.

**Keywords:** cognitive ergonomics, bowtie, offshore labor, human factors.

**RESUMO**
A ergonomia é uma ciência que trata da organização do ambiente de trabalho visando à segurança e à saúde do homem. No entanto, os conceitos ergonômicos no cenário atual seguem, principalmente, aspectos antropométricos (posturas, mobiliário, equipamentos, transporte de cargas) e condições ambientais (temperatura e raios, por exemplo) e ainda são fracos do ponto de vista cognitivo, que abrange processos mentais como percepção, memória e raciocínio. Esses conceitos são fundamentais, principalmente em ambientes de trabalho complexos e, por isso, o caso escolhido neste estudo foi o do trabalho offshore. O risco de acidentes graves é inerente aos trabalhadores em toda a temporada de embarque, e eles vivem suas folgas em condições de confinamento e isolamento, pois não é possível ir para casa após o trabalho ou entrar em contato com familiares e amigos, exceto com os dispositivos disponíveis na unidade. O objetivo desta pesquisa é a adaptação de uma ferramenta, a técnica BowTie Analysis (BTA), para incluir fatores humanos e aspectos cognitivos. Dessa forma, por meio de uma metodologia de baixa complexidade, essa abordagem poderia ser aplicada no gerenciamento de riscos de plataformas de petróleo e gás, preenchendo uma lacuna que ainda precisa ser abordada. Para expandir os aspectos cognitivos para além das salas de controle, foi escolhida uma atividade importante que também tem interação homem-máquina e onde podem ocorrer muitos acidentes nas plataformas: a operação de guindastes. Espera-se que esse exemplo impulsione o desenvolvimento, ou a adaptação, de novas ferramentas, a serem implementadas no gerenciamento de riscos das plataformas de petróleo, visando a uma maior segurança na realização das atividades laborais, deixando o trabalhador de ser visto como um "problema" no complexo sistema, já que a maioria das causas de acidentes é atribuída a erros cometidos pelos trabalhadores, erros esses que podem e devem ser estudados e absorvidos pelos sistemas de segurança, que devem ser projetados e construídos para prever e agir antes que as falhas humanas mais comuns aconteçam. Assim, a jornada de trabalho dos profissionais que atuam nas unidades petrolíferas offshore poderá ser cada vez mais saudável e segura, como toda vida deveria ser.

**Palavras-chave:** ergonomia cognitiva, bowtie, trabalho offshore, fatores humanos.

**1 INTRODUCTION**
Ergonomics, a word of Greek origin that unites ergo (work) and nomos (standards) is a science that deals with the organization of the work environment aiming the safety and health of the human being [1]. The ergonomic evaluation of
work activities is a recent practice, and it is still in progress.

The ergonomics concepts in the current Brazilian scenario follow mainly the Ministry of Labor and Social Safety Regulatory Standard No. 17 that covers, for the most part, anthropometric/biomechanical aspects (postures, furniture, equipment, cargo transport) and environmental conditions (temperature and lighting, for example), but are still very incipient from the cognitive point of view, related to mental processes such as perception, memory and reasoning. According to the Brazilian Association of Ergonomics (ABERGO), this topic of study should also assess the mental workload, decision-making, performance, human-machine interaction and stress, among other factors.

As these concepts are fundamental, especially in complex work environments the field chosen for this study was the offshore (production platforms and drilling rigs included). Figueiredo, 2016, in his book “The Hidden Face of Black Gold – Work, Health and Safety in the Offshore Oil Industry of the Campos Basin” [2], describes in a precise way the main specificities of this activity: danger, complexity in continuity, in a collective dimension. The risk of serious accidents is inherent and workers spend the entire boarding season working and living their time off under these conditions of confinement and isolation, since it is not possible to return home at the end of the day, nor is it easy to contact family and loved ones. In addition, there is the idea that, in case of accidents, even with the modern rescue systems, assistance may not arrive in time, since, beyond the usual impasses for this type of situation, there are others that can difficult the proper treatment access, such as climatic problems, for example.

Even with all these items, Cognitive Ergonomics is not a routine theme in oil and gas offshore industry and these companies need to be encouraged to carry out studies on this subject.

It is expected the implementation of this tools in the safety analysis of oil platforms, aiming greater safety and comfort in the labor routine. Besides, as has been seen in inspections carried out on platforms over the last ten years, the worker can no longer been seeing as a “problem” in the system, as he is the one who usually makes mistakes or fails, which is usually seen in accident investigations, where most of the causes are attributed to unsafe acts.

1 “A Face Oculta do Ouro Negro – Trabalho, Saúde e Segurança na Indústria Petrolífera Offshore da Bacia de Campos”
The objective of this work is to amplify human factors and cognitive aspects approach in production platforms and drilling rigs using a tool that can be easily understand, as these are themes are subjective and still unknown by both workers and companies. So, it was chosen the Bowtie Analysis. In this way, cognitive issues can be disseminated from a known tool used in risk management.

To achieve this objective, the following steps were considered:

• Bibliographic review related to Cognitive Ergonomics and Human Factors in the Offshore Industry.
• Review of international and Brazilian standards on the subject.
• Study of the Bowtie tool.
• Identification and description of the offshore environment to be analyzed.
• Elaboration of Bowtie diagram, encompassing human factors and cognitive aspects, in a case study (loss of load control in cargo handling activity).

2 MATERIAL AND METHODS

2.1 CONTEXT

Oil exploration is one of the most dangerous activities in the world. The 2016 Statistical Report, from the WOAD (Worldwide Offshore Accident Databank) database, produced by the Norwegian Classifier DNV (Det Norske Veritas) [3], which associates information of all accidents occurred in the offshore and oil and gas industries in the world from 1970 to 2012, reports the occurrence of 6,451 accidents, 6,045 directly linked to platforms. The document highlights that there is a considerable number of accidents that are not reported. So, the actual number of events can be even higher.

Another data source, the Health and Safety Observatory of the Public Ministry of Labor [4], reports the issuance of 7,172 CAT² (Communications of Work Accidents) in activities related to extraction of oil and natural gas, and 6,299 CAT in the oil extraction activity, totaling 13,471 communications from 2012 to 2021.

Such data demonstrate that many accidents still occur in Brazil and in the world, requiring the development of tools to improve the Safety Management

² Comunicação de Acidente de Trabalho is the name in portuguese.
Performance in the oil industry, especially offshore.

2.2 WORK ON OFFSHORE PLATFORMS

Labor in offshore environments is characterized by a considerable number of risk activities occurring at the same time and often in proximity. They can even occur in confined spaces, where there is a limitation in the ambient air renovation. It is also possible to occur exposure to dangerous agents, such as physical (noise, heat, vibration, ionizing and non-ionizing radiation), chemical (flammable, explosive, asphyxiating, toxic, carcinogenic substances etc.) and even biological (viruses, fungi and bacteria), in the sharing of closed spaces.

According to Figueiredo, 2016 [2], it should also be considered sleeping disorders, stomach problems and other harms caused by stress, lack of privacy, work shifts and constant exposure to noise (often even in cabins). It cannot be forgotten the risk of explosions, fire, leakage of toxic gases (such as H2S, benzene, carbon monoxide, ammonia etc.), electrics issues, contact with too hot or too cold surfaces, crushing, drop objects, weather conditions and the possibility of helicopter crash, all in the same environment, that could be called hostile.

According to ANP³ (Brazilian Petroleum Agency) [5], there are 63 platforms in operation in the country, involving thousands of workers, performing at least in 14 consecutive days, in daily 12-hour shifts (usually from 6:00am to 6:00pm or from 7:00am to 7:00pm) and 12 resting hours, inside the vessel accommodation and with little contact with the outside world, leaving the person practically out of the social context during this time. In addition, if it is necessary, the worker can also be called during his rest period.

Furthermore, if in the disembark day the weather conditions make impossible the helicopter to fly, the replacements may not arrive, and the worker that have ended the season on the platform have to resume their stations until flights restart.

So, the work organization in an offshore environment is fundamental for maintaining both safety and the workers well-being during the boarding period. They need to be supported by a Health and Safety Management efficient and effective.

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³ Agência Nacional de Petróleo is the name in portuguese
Furthermore, the offshore oil industry is considered a complex socio-technical system. Sociotechnical, as it associates the individuals with technical instruments used in the work activity. And complex because in continuous processing industries non-linear interactions predominate, which can be multiplied when a subsystem is activated. In other words, there are numerous associated connections that, in case of failure, can cause accidents due to the unpredictability of the multiple interactions that can occur. Therefore, accidents can happen through the systems part's combination, even if no specific component has stopped working in the way it was designed for. [6]

After understanding the reality of offshore work, especially on oil and gas platforms, and how the work organization is fundamental, mainly in this type of complex socio-technical system, it will be proceeded to verify the application of Cognitive Ergonomics and its contribution to Safety at Work.

2.3 COGNITIVE ERGONOMICS

Contemporary ergonomics encompasses physical, cognitive and organizational aspects.

The physical part, coming from the Anglo-Saxon school, assesses the limits and capabilities of the human body and uses concepts of anthropometry/biomechanics. It also considers environmental conditions, such as temperature, acoustics, lighting, and how man interacts with his workplace. It studies postures, repetitive movements, manual loads handling and use of force [7].

The organizational function contextualizes the organization, involving tasks distribution over time, communication, routines and procedures establishment, performance requirements and standards, supervision and control systems, work recruitment and selection mechanisms and methods of education and training.

The cognitive approach, originated from the French school, considers the mental capacity of the human being in the development of work. It is dedicated to the study of mental load, perception, reasoning, the decision-making process, human-machine interaction, stress, training etc. It covers usability, human reliability and systems operability.

It is necessary to understand the interrelationship of the human brain with the environment. For this, in the cognitive analysis, aspects such as the workers'
stress level, cognitive capacity, motivation level, competence degree and the shifts influence in the work performed should also be considered [7].

A person performs a task through activities that integrate the body and intelligence in order to achieve certain goals under specific conditions. Therefore, the form of execution depends on the context, health conditions, organizational environment, tools, professional relationships, goals to be achieved, and workplace physical conditions, among many other variables [8].

Man's relationship with work can be evaluated through the relationships that an operator establishes with his task. Work instruments and machines are the worker information sources, who uses his sensory organs to interpret and decide the action he will take to achieve the requested demand. Immediately, the chosen action becomes a source of new information to be detected and treated by the operator, creating a man-task chain.

Input information comes from the task and the work environment, and it is captured by sensory organs. The mental functions used can vary between detection mechanisms (receiving information), identification (distinguishing between useful and useless information) and interpretation (giving meaning to information). Memory, based on the experience, must also be considered.

Decision making is a result of these mental operations and can be manifested in several ways: movement, waiting, order etc. In other words, mental activity prepares and commands physical activity, and both are intrinsically linked, since a deficient treatment of information can lead to an inappropriate act.

Unlike the physical part of work, which is possible to observe, describe and decompose, the sensory activity of work is not apparent. However, it exists in all activities, even in the simplest. Therefore, the activity is composed of an observable part, the visible behavior, and a non-observable part, related to experience, emotional state, physical condition, individual sensitivity and reasoning. [8]

“To be able to carry out his task, a person has to perceive the environment stimuli, receive the information from others, decide which actions are appropriate, carry out these actions, transmit the information to other people so that they can do their tasks etc.” [9]
These actions: perception (or observation), interpretation (or evaluation), decision (or planning) and execution (implementation), resulting from study from HOLLNAGEL and CACCIABUE, 2021 [10], are the ones that must be worked on in the task analysis, if evaluated from a cognitive point of view.

2.4 HUMAN FACTORS

According to Waterson and Eason, 2017 [11], during the 60s the ergonomics that was being developed in the United Kingdom also started to consider automation and the need to understand aspects as management, technology and machine x man at work. At the same time, the term "human factors" or "human factors engineering" was used in the United States, under the influence of psychology and engineering.

The term “human factors” has already been considered synonymous with ergonomics, as both were multidisciplinary themes and related with the interaction of human beings with the technological elements of the work environment.

According to Dejours, 1999 [12], “human factor” is the expression used by professionals in the engineering area to designate the men and women behavior at work, being associated with the idea of error or operators’ failure. In other words, it starts from the principle of absolute trust in science and technology.

Costa, 2014 [13] follows the same line when stablish that the first industrial accidents studies did not focus on accident prevention and did not expand the vision for the circumstances and determinants of the activities. As consequence, accidents were seen as the result of workers' failures, who were in the wrong place, at the wrong time and/or adopting the improper conduct, that is, the human error. However, when studies began to analyze technical systems, it was realized that it is not possible to change human nature and that, therefore, people fail, and mistakes happen. So, barriers were directed to act in the activity’s execution.

As described by Carayon et al., 2017 [11], different human factors approaches in sociotechnical systems have appeared over the years, such as macro ergonomics (Hendrick and Kleiner, 2001), activity-related ergonomics (for example, Daniellou and Rabardel, 2005), user-centered approach (Booher, 2003) and human factors engineering (Moray, 2000; Wilson, 2000); each one with its...
methodology and individual x system performance evaluation.

In the field of research, it can be mentioned Cahill et al, 2019 [14], who have studied the improvement of the Boeing company software (called Surface Operations Collision Awareness System – SOCAS), that is used for maneuvering and taxiing aircrafts, through human factors approach, working the Performance Shaping Factors (PSF), that is, the factors that influence human behavior. External PSF cover environmental conditions, equipment design, procedures and poor supervision. The internal ones include emotional state, stress level, physical conditions, experience and knowledge in the task to be performed. It was concluded that the adaptation of the SOCAS system could provide the correct information to the pilot (or to another relevant agent) and predict actions to be taken to prevent human error.

Also using PSH, but now focused on the Norwegian oil industry, Taylor et al, 2018 [15], developed the PETRO-HRA method, which studies the human contribution in the oil industry risk. The conclusion is that this method improves the security analyses quality.

Islam et al, 2017 [16] conducted a survey relating human factors to maintenance in marine systems, in order to avoid accidents and increase the machinery useful life. As such maintenance is done by maritime workers, it can certainly happen human errors. The methodology used was divided into three stages: 1) Activity identification (the maintenance of the cooling water pump and the anchor windlass were used as the case to study) and the category of seafarer responsible for carrying it out. The category is defined through the relation between training, experience and level of fatigue; 2) Selection of internal and external factors that could lead seafarers to error during maintenance activities. The internal factors would be training, experience and fatigue and the external ones consist in environmental conditions (climate and temperature at the workstation) and operational conditions (vessel movement, workload, stress, noise and vibration). The decision of the factors was based on previous studies and in the experts and seafarers’ opinion; 3) Application of the Bayesian Network (BN) mathematical model to estimate the Human Error Probability (HEP). The conclusion of the research is that the chosen methodology can demonstrate the dependencies between the factors that impact the performances and seafarers’ actions during maintenance activities, being effective and better than other existing techniques.
for calculating human error probability. Thus, through this technique, the commander or person in charge can select the most suitable professional to carry out each activity under certain conditions, aiming accidents reduction.

Objecting to provide an overview of how human factors engineering is being implemented in the planet's offshore industry, Chandrasegaran et al, 2020 [17], developed a study on the subject, reaching the conclusion that, despite the existence of considerable human factors material, its effective use in design, construction and operation has yet to be consistently demonstrated. Some of the reasons given would be inadequate understanding of rules and regulations and lack of proper allocation of resources.

2.5 THE BOWTIE TOOL

Schmitz et al, 2019 [18] report that one of the several techniques developed for risk management is the Bow-Tie Analysis (BTA), which illustrates the relationships between barriers and management factors. At the heart of the scheme is the danger, which, if left unchecked, becomes an event, with consequences.

According to Khan et al, 2015 [19], the Bowtie takes this name because the diagram has the shape similar of a bow tie. And this is an emerging method that is already being used in most chemical process industries.

Bowtie Analysis was developed by combining “fault trees” and “event trees” analysis methods in the early 70s. It consists in elements such as hazards, top event, threats, consequences and controls (preventive and mitigating), organized in a bowtie format (Figure 1). It has been extensively used in critical systems such as chemical, petrochemical and mining industries.

Yazdi, 2017 [20] informs that the exact origin of the Bowtie method is not completely clear. Some reports indicate that it was created from the development of cause-effect diagrams. Others say that David Gill of Imperial Chemical Industries PLC (ICI) developed the technique, which was renamed "Bowtie" in the late 1970s.

In the early 90s, the use of this technique increased substantially, after the accident on the Piper Alfa platform, owned by Royal Dutch/Shell, which started to adopt this tool in its commercial activities. Its approach is most common in the analysis of safety-related risks when it is impossible or difficult to quantify the risk,
and it is currently widely used in different types of industries to improve safety performance.

Risk, in the Bowtie methodology, is the relationship between hazards, main events, threats and consequences. Barriers are used to demonstrate the measures that the organization has in place to control it.

![Fig. 1 – Bowtie Diagram Model](from Verschoor, 2019 [21])

Bowtie elements are: [22]

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
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<tbody>
<tr>
<td><strong>Hazard</strong></td>
</tr>
<tr>
<td><strong>Top Event</strong></td>
</tr>
<tr>
<td><strong>Threats</strong></td>
</tr>
<tr>
<td><strong>Consequences</strong></td>
</tr>
<tr>
<td><strong>Barriers</strong></td>
</tr>
</tbody>
</table>
A barrier must be effective, independent, and auditable. Active barriers must contain the three elements of detect-decide-act. A barrier can be any measure taken that acts against some undesirable force or intention in order to maintain the desired state.

Source: Authors

There are certain conditions that can cause barrier failure, called escalation factors. An escalation factor is a condition that leads to increased risk by defeating or reducing the effectiveness of a barrier. For example: earthquake that leads to cracks in the concrete floor around a pipe. Escalation factors are also known as defeating factors or barrier decay mechanisms.

The barriers must be managed to maintain their effectiveness through time. If the hazard becomes unmanageable and triggers the central event, the consequences will follow quickly. That is, the left part of the Bowtie schema might take days, months, years, or even never happen, but if the main event occurs, the right part of the schema could only take a few seconds.

The BTA has been extensively used in critical systems, such as chemical, petrochemical and mining industries. Authors such as Chevreau et al, 2006, apud Stemn et al, 2017 [23] believe that this technique can also be used as an effective tool in communicating security issues. They tested the Bowtie method for filtering learning gaps in the accident literature, identifying key areas that can improve learning, as incidents continue to occur around the world despite security investments made by corporations.

These learning gaps demonstrate a failure in processing previous events. LFI (Learning From Incidents) refers to the ability to gain knowledge from past events and transfer it to practices and behaviors that can prevent future events, assisting for the overall safety improvement. Learning failures are related with to two things: lessons that were not learned or lessons learned that were not efficiently integrated. Much research on the subject has already been developed, the most recent being related to cognitive systems.

Stemn et al, 2017 [23] research used the BTA approach to organize lessons learned into three themes: threats to learning, consequences of learning failures, and interventions needed to prevent or mitigate failures in learning from incidents.

Nunen et al, 2018 [24] add that the security barriers of the Bowtie diagram can include technical, organizational and human factors.
McLeod, R.W. and Bowie, P, 2018 [25] identified that there is confusion in the BTA technical literature, since, as its visual representation assumes a linear model, many argue that it is inadequate as a means of understanding the dynamics of accidents in the complex sociotechnical systems. However, it is important to recognize that, adopting BTA concepts and frameworks, there is no need to make assumptions about the mechanisms and processes that lead to this incidents, and this is one of the most significant differences between BTA and techniques such as Failure Modes and Effects Analysis (FMEA), Event Tree Analysis (ETA) and Root Cause Analysis (RCA), which explicitly assume that adverse events can be modeled as a sequence of linear relationships and causal interactions between system elements. It is true that many BTA users are based on a linear traditional model of technical systems driven to events and how they fail. It is also true that BTA has been used in ways that often seek to identify and assess barriers that are able to block what is been modeled as a linear events chain between underlying causes and top events [25]. However, it is not necessary to make assumptions about the mechanisms that may stand in the way between threats and top events and the consequences they may lead to. There is no reason why a Bowtie model cannot be based on a STAMP (Leveson, 2011) or FRAM (Hollnagel, 2012) analysis, for example. In short, when executed properly, BTA can provide a rich understanding of the controls that must be in place to protect against incidents, how they can fail, and how they need to be implemented, monitored, and managed.

According to Liu, 2020 [26] barrier management interacts with many other aspects related to safety, environment and asset management. Some barrier systems consist in an integration of hardware, software and humans, such as some shutdown operations that are completed manually based on alarms from temperature or pressure transmitters. Therefore, human and organizational factors can affect the barriers. McLeod, 2017 [24] highlighted some reasons: 1) human thinking and performance are influenced by situation and experience; 2) some technical issues can affect the way people behave and interact with technology; 3) people are inclined to finding the easiest way to do things, even if it generates more risk and 4) It is difficult to assume that people are always rational. Therefore, Human and Organizational Factors need to be coordinated to increase the reliability of technical systems barriers.

There is specific software for the Bowtie method (the BowTieXP), whose
Manual was updated in 2019 [27]. According to this, the methodology is used for risk assessment, management and communication. The method was designed to give an overview of the situations in which risk is present, helping people to understand the relationship between risk and organizational factors, in a simple way, making it as easy as possible to understand and apply.

3 THE COGNITIVE BOWTIE APPLICATION

3.1 CHARACTERIZATION OF THE ACTIVITY TO BE ANALYZED

As control room activities are the most studied in the Cognitive Ergonomics, it was sought another activity in the industry offshore oil company in which man x machine interaction is fundamental. And as without cargo handling activities the operation in platforms cannot happen (because the basic issues, as the workers food, do not arrive), accidents in this area can be avoid as hard as possible. So, it was chosen the crane operator.

It is important to emphasize that many accidents with cranes can occur, and it is essential to observe, in addition to the mechanical and machine aspects, the Human Factors. In fact, Human Factors must be studied intrinsically in all work activities, and the offshore workforce cannot be forgot.

Each oil platform has at least two cranes, which are the main devices for handling internal loads and transporting cargo from supply ships to the unit. All kinds of materials and inputs arrive through them, such as the food that is consumed by workers. In addition, they also dispose of what is no longer needed in the unit. In other words, its constant operation is fundamental [28].

Also, according to Abraçado, 2013 [28], the crane operator is responsible for handling the equipment. He participates in almost all cargo handling activities, maintaining radio contact with the area team all the time. He is also the professional responsible for the conservation of the equipment devices and, therefore, must carry out primary maintenance, such as oil change, lubrication and cleaning. In addition, do the daily crane inspection, filling out a checklist that will serve as a guide for the necessary corrective maintenance, that is performed by the maintenance team.

It’s not easy to work as a crane operator on the high seas. The constant movement of the vessels makes the task of keeping the equipment centralized in relation to the load more difficult, causing a pendulum movement that can generate
collisions. In addition, factors such as winds, waves, sea currents and reduced visibility affect the professional's service [29].

There is the possibility of moving dangerous loads or the ones essential for survival on the platform, such as food and water for consumption, increasing this worker responsibility.

It is such an important activity that Petrobras, the major Brazilian oil & gas company, since 2009, has crane simulators in Macaé, a city in the Rio de Janeiro state [30]. Other companies and entities also have simulators.

According to the Brazilian Occupational Code (CBO⁵), developed in 2002 by the then Ministry of Labor [31], the brief description of the crane operator position (fixed) is as follows:

“They operate machinery and lifting equipment, adjusting commands, triggering machine movements. Evaluate machines and equipment operating conditions, interpreting the measurement instrument panel, verifying power supply, testing activation commands. Prepare the area for equipment operation and transport people and materials in machines and lifting equipment. Work following safety, hygiene, quality and environmental protection standards.”⁶

Once the activities usually performed by the crane operator have been defined, as well as the main factors that may interfere with the work routine, the cognitive aspects that can be addressed in the proposal for the preparation of the Bowtie in question will be highlighted.

3.2 COGNITIVE ASPECTS USED IN BOWTIE ANALYSIS

From the cognitive ergonomics point of view, in the analysis of work, it is important to understand how the worker perceives and acts, according to the information he can capture in the environment around him. That is, how mental processes occur in situations that lead to decisions and, consequently, actions. These perceptual and cognitive processes, also called “human cognition”, allow human beings to seek, treat, store and use stimuli (information) from the

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⁵ Código Brasileiro de Ocupações, in Portuguese
⁶ “Operam máquinas e equipamentos de elevação, ajustando comandos, acionando movimentos das máquinas. Avaliam condições de funcionamento das máquinas e equipamentos, interpretando painel de instrumentos de medição, verificando fonte de alimentação, testando comandos de acionamento. Preparam área para operação dos equipamentos e transportam pessoas e materiais em máquinas e equipamentos de elevação. Trabalham seguindo normas de segurança, higiene, qualidade e proteção ao meio ambiente."
environment.

According to St. John, 2017 [32], the Cognitive Bowtie can be a simple alternative approach to identify the Human Factors that can support key decisions in process control. It is a tool that focuses on major hazard-related decisions and analyzes these decisions in terms of the decision cycle (detect, interpret, decide, and act) and the cognitive human factors that affect them (Figure 2).

Fig. 2 – Example of Decision Cycle and the human factors that can be associated

First, a problem is detected. Then, the situation is interpreted to identify and understand the problem. A decision is made to solve the situation, followed by its implementation. These steps form a continuous cycle as the impacts of the action are detected and interpreted and further decisions are made.

According to this, the following failures can be foreseen, to be considered in a Bowtie Analysis:

<table>
<thead>
<tr>
<th>Cognitive Function</th>
<th>Possible Failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation</td>
<td>Observe the wrong object</td>
</tr>
<tr>
<td></td>
<td>Observe with delay</td>
</tr>
<tr>
<td></td>
<td>Do not observe (omission)</td>
</tr>
<tr>
<td>Interpretation</td>
<td>Fail in the diagnosis</td>
</tr>
<tr>
<td></td>
<td>Interpret with delay</td>
</tr>
<tr>
<td>Planning</td>
<td>Prioritize planning steps wrongly</td>
</tr>
<tr>
<td></td>
<td>Plan in a wrong way</td>
</tr>
<tr>
<td></td>
<td>Plan in an incomplete form</td>
</tr>
<tr>
<td>Action</td>
<td>Execute incorrectly (excessive force, wrong direction, speed above or below necessary)</td>
</tr>
</tbody>
</table>
### 3.3 BOWTIE ASSEMBLY

In the chapter 4 of Bowties in Risk Management CCPS book [22] it is said that in Bowties, Human and Organizational Factors (HOF) can appear in many places: as threats (human failures), parts of an active prevention or mitigation barrier, degradation factors or as parts of a degradation factor control. It can also form a barrier element if it is effective, independent and auditable. So, if it acts as a full prevention barrier the human activity must be capable of terminating the threat pathway on its own.

St. John, 2017 [32], believes that with the cognitive approach Bowties will focus on the key decisions to control hazards, prevent top events, and prevent or minimize consequences. Each key decision is then evaluated against the human factors from the decision cycle. It can identify key decisions within a process and then examine the factors that affect the quality of those decisions. The human factors in the decision cycle act as barriers against poor decisions. Strong human factors, such as attentive and non-fatigued operators and good team communication skills act to prevent poor decisions. Weak human factors allow poor decisions to be made and top events to occur.

In other words, strong physical barriers control and contain energy and prevent hazards. Strong human factors barriers prevent poor decisions.

In this study it was identified as Hazard the “load suspended by a crane” and the Top Event “dropped load by the loss of control during a movement activity with the crane”, being identified three main consequences:

1) Damage to the load. AND/OR
2) Damage to the vessel, which may or may not be structural. AND/OR
3) Harm to people. In this case, a physical barrier, the impediment to the access area under the influence of transport, using delimitation resources, is possible.

Since the use of cranes under adverse weather conditions is not allowed (which would be one of the causes of loss of control), the other two main causes

<table>
<thead>
<tr>
<th>Cognitive Function</th>
<th>Possible Failures</th>
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<tbody>
<tr>
<td>Run at the wrong time (too early or too late)</td>
<td></td>
</tr>
<tr>
<td>Activate the wrong control (buttons, cranks, etc.)</td>
<td></td>
</tr>
<tr>
<td>Act outside the planned sequence</td>
<td></td>
</tr>
<tr>
<td>Do not act (omission)</td>
<td></td>
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</tbody>
</table>

Source: Authors
that will be studied are:

1) Equipment failure (crane).
2) Overload.

For each of them, the four items of the decision cycle were considered: detection, interpretation, planning and action. Threats related to human factors were placed in verb (actions), with the respective barriers (Figure 3):

As the focus is on the inclusion of cognition and human factors items, other causes not directly associated with the decision cycle, such as maintenance items, design etc., will not be addressed.

Figure 3 – Bowtie diagram of the case of study – barriers related to the decision cycle

(by the author).

Overload:

In the detection (observation) stage, a strong barrier would be the use of an alarm. However, in addition to equipment failure (which can be treated with maintenance and testing routines), two cognition threats can be considered, according to the possible failures in raised in Chart 1:

1) Non-observance of the alarm, which can occur due to a design failure (and can be solved by placing a visual and audible alarm positioned in the operator’s vision zone) or due to operator fatigue, that may be treated by the verification of the work hours and the valuation of work overload.
2) Delay in the observance of the alarm, and the two barriers to be applied are like chosen one for non-observance.

Once the excess load is detected, the veracity/severity of the situation must be interpreted. In this case, it is possible:
1) Delay in interpreting the alarm information, which can also occur due to operator fatigue, caused by excessive working hours, overload, stress etc. So, all these human factors must be previously treated and observed.

2) Interpret the alarm wrongly, deciding that it is still possible to move the load. For this threat, operators experience and training are the main barriers, translated into simulations; tools that enable the exchange of experiences between operators (such as creating a database); and scope of other similar incidents, in the same unit or even in others. In addition, the availability of weight tables in the crane cabin is an easy barrier to implement, which can be very useful in interpretation. Interpreting the load excess, it is possible to fail in the:

1) Decision to continue, which can also be controlled by barriers associated with experience and training.

2) When “Stop Culture” is deficient and the operator feels the obligation to continue for fear of “delaying the service” or even of being punished and considered “too careful”. For this, there must exist robust procedures and an incentive to stop service whenever the operator identifies that there might exist a safety problem.

3) Delay in the decision to stop, a threat many times caused by the insecurity of the operator. The barriers would be the same as those previously identified: reinforcement in training and in the exchange of experiences and a robust “Stop Culture” policy.

Once the barriers of detection x interpretation x decision are overcome, if the operator decides to continue the operation, the probability of occurrence of the main event (loss of load control) becomes very high.

Or even it can happen if the operator notes that there is a problem and decide to stop, but push the wrong button due to a confusing button panel design (confusing button colors, tags, identification etc.).

Crane failure:
Considering the possible failures in the cognitive functions raised in Chart 1:

For failure detection, the main barrier is the prior verification whenever the equipment is used, with completion of a checklist. In this case, the main threat would be not to observe the failure, either due to lack of training/experience, or
fatigue, making it necessary to work on these two barriers. The existence of robust procedures or the use of a dual check (operator and supervisor) would be barriers to be applied.

Once the failure is observed, it must be interpreted, deciding if it would inhibit the equipment operation. The main misinterpretation would be the delay, which would reduce the reaction time. This delay would be mainly linked to training/experience, two items that can also be used as a barrier in the decision of stop or not the operation. The barriers to this decision also include training/experience, but they are also procedural and related to “Stop Culture”. Taking the decision to continue without the necessary security, the probability of loss of control of the load increases considerably.

4 CONCLUSION

The objective of this work was to associate the Bowtie tool with cognitive and human factors aspects, using as an example the operation of cranes on an oil and gas platform. For this, the topics “Cognitive Ergonomics” and “Human Factors” in the offshore industry in the world have been studied, as well as international and Brazilian standards on the subject and the Bowtie tool itself. After that, the case study to be treated was chosen (loss of load control in handling activity with the use of crane) and proposed to Bowtie, using the four cognitive functions of the decision cycle - observation x interpretation x planning and action, such as barriers to prevent the Main Event. Threats (human errors) were identified for each of them, and measures related to human factors were used as “cognitive barriers” to prevent possible human errors within the decision cycle functions.

It was concluded that this adaptation is possible, and the Bowtie tool is indicated to work together with Human Factors and Cognitive Ergonomics, especially considering its low complexity, which allows it to be worked together with workers.

It is expected that this, and other similar tools that make it possible to approach the cognitive aspects and human factors in the work on oil platforms, are increasingly disseminated, applying the concepts already existing in the literature and in regulation and legislation, enabling, including its improvement.

In addition, once provoked, companies in the field are expected to develop their own procedures and practices to insert these aspects into their studies of
health and safety at work, improving their approach.

Finally, it is expected that the concepts of Cognitive Ergonomics and Human Factors are included in the Brazilian labor reality.
REFERENCES


[29] https://opetroleo.com.br/como-trabalhar-embarcado-como-operador-de-
Studies in Health Sciences, Curitiba, v.4, n.2, p. 419-442, 2023


