Human Factors approach to Process Safety in the Offshore area using FRAM

Josué Eduardo Maia França
Kalmar Maritime Academy, Linnaeus University, Kalmar, Sweden
josue.maia@gmail.com

Erik Hollnagel
Patient Safety Department, University of Jönköping, Småland, Sweden
hollnagel.erik@gmail.com

Prepared for Presentation at
American Institute of Chemical Engineers
2020 Spring Meeting and 16th Global Congress on Process Safety
Houston, TX
March 30 - April 1, 2020

Human Factors approach to Process Safety in the Offshore area using FRAM

Josué Eduardo Maia França
Kalmar Maritime Academy, Linnaeus University, Kalmar, Sweden
josue.maia@gmail.com

Erik Hollnagel
Patient Safety Department, University of Jönköping, Småland, Sweden
hollnagel.erik@gmail.com

Keywords: Human Factors, FRAM, Process Safety, Risk Assessment

Abstract

The offshore exploration, drilling, and production, in O&G industry, are one of the most necessary activities of human Society. However, since its beginning in North America, the process variables - such as temperature, pressure and depth - have increased their operational parameters considerably, leaving the 21 meters deep, on land in 1859, extremely remote from the 6.500 meters in offshore area of Brazil Pre-Salt. To drill a subsea well and raise the crude oil to a platform, by itself, presents a series of risks that compromise the Process Safety of the entire plant. Avoiding a loss of containment, in addition to being inherent to safety itself, is also in the interest of the environment, production control and workers' health. In this sense, understand the safety barriers, as well as comprehend the Human Factors involved in Process Safety, not only brings operational reliability to the plant, but also meets the requirements of the legislation and increases productivity. In this research, a FRAM was developed to analyze a loss of containment of an FPSO storage tank, showing the importance of a systemic understanding of Human Factors in Process Safety, acting as an effective barrier to the security of the entire process.

1 Introduction

The offshore O&G industry, compared with most energy industries, is marked over time by major accidents, catastrophes at sea that marked the History and the industry itself. The two largest accidents in the production offshore area, was on the production platform Piper Alpha in the UK sector (167 fatalities) and the semi-submersible Alexander Kielland in the Norwegian sector (123 fatalities), have contributed about half of the total number of fatalities since offshore activities began in USA West Coast [1]. These accidents are characterized as typical process accidents, where a LOPC, staggered over time, becoming a major loss of containment, explosion and, consequently, the destruction of the entire platform. And despite all technology, automation and system barriers, process accidents still can occur due the gradual increase of interactions and complexities in the current work environments of the offshore production area. In these scenarios, not every situation can be foreseen or anticipated, once there is not a checklist or prediction for everything, relying in the resilience of the system the solution for emergence and non-planned routine situations. Aiming to understand this resilience, and how it reflects on the principles of Process Safety, it is necessary a wider comprehension, that includes the interaction between workers, equipment, and systems. In this sense, the development of a Human Factors approach to Process Safety in the production area of a FPSO, using FRAM, not only contributes to process safety, but also to safety as a whole. Understanding the work, the elements that act in this performance – individual, organizational, technological, and environmental – reflects in the safety itself as well as in the productivity, protecting and ensuring the operational performance of the entire industrial process plant.

2 Systematic Understanding of Human Factors

The understanding regarding Human Factors in the industry is becoming essential for technicians, managers, and companies to not only promote safety but also to understand how system complexity and interactions between factors can affect present and future work. However, an important question remains, which is how Human Factors can be adequate recognized and managed. The first step to answer this question is the comprehension of how the interactions between workers and technological artefacts were developed in the industry. One of the first records regarding the interaction between the so-called complex machines and operators were when the first armor tanks were introduced in the final years of first world war. Initially called "vehicles for rapid assault and transposition of trenches" the first tanks, though basic compared to current military and civilian vehicles, were at that time a technological paradigm for soldiers accustomed to bayonets, horse saddles and trenches. On the other side of the enemy lines in the East, the technological contrast was even greater, for the most technological one in the Ottoman-Turkish Empire was bows and arrows [2]. Rapidly this interaction migrated from land do air, still in the first world war, with the introduction of military aircraft, which became even more complex in World War II, where the "failures" of pilots who were not fit for these aircraft became even more evident [3].

The concepts of human reliability and the definition and early measurements of human error had started with the empirical theories of Heinrich, being more scientifically developed by other authors, and marked the risk assessment theories and industrial accidents in much of the 20th century, especially the accidents of Three Mile Island – TMI (1979), Bhopal (1984) and Piper Alpha (1988) [4]. This concept placed an understanding of Human error is considered a part of everyday functioning and it is expected that people will make errors [5]. The traditional human reliability analysis covers few stages in the so-called human error identification, such as identifying human act, modelling of significant human action, and evaluating human action probabilities. However, these methods have fundamental limitations to introduce all the significant aspects of human performance due to insufficient data, subjectivity of analysis and uncertainty, which shows a need of a clear understanding of how human performance happens, in a daily basis routine [6]. In this sense, few studies postulate that human errors are practically always involved in accidents and continuous efforts to reduce human errors have placed increased emphasis on training, motivation, hardware design, and management systems, in a pursuit for eliminate, or at least reduce, the so-called human error [7]. From the core of these studies, a new perspective regarding human error and accident analyses revealed factors that were related to the human performing the task, but was not directly related to individual issues, so the focus shifted to organizational factors, such as management and safety culture, which form many of the conditions in how the work is done in the sharp end, like training, staffing and high work pressure. This new perspective understand that Human Factors are directly linked to human performance, with positive or negative outcomes, depending on how the variability, and results, of the human outputs are interpreted.

Human performance is part of the human reliability studies, although from a different perspective from the current human performance studies, where the concepts of Human Factors are sedimented. Aiming for a balance perspective [8] postulates that Human Factors is about the understanding of the relationships between demands and capacities in considering human and system performance (i.e., understanding human capabilities and fallibilities). The term is used much more in the safety context than ergonomics even though they mean the same thing very much. Like Human Factors, ergonomics deals with the interaction of technological and work situations with the human being. Anatomical, physiological, and psychological knowledge/data are applied to achieve the most productive use of human capabilities and the maintenance of human health and well-being. The job must 'fit the person' in all respects and the work demands should not exceed human capabilities and limitations. Its meaning is hard to distinguish from Human Factors, however, is often associated more with the physical design issues as opposed to cognitive or social issues, and with health, wellbeing and occupational safety, rather than with the design of major hazard systems.

Seeking to integrate and comprehend technology and behavior, Human Factors engineering (HFE) came as a discipline that work in the interaction between humans and technology, as well as system and process, especially for the Nuclear Industry. The aim of that was to seek, discover and apply knowledge about human capabilities and limitations to system and equipment design, ensuring that the system design, human tasks and work environment are compatible with the sensory, perceptual, cognitive and physical attributes of the personnel who operates systems and equipment [9]. After the accident at TMI, a critical review of plant design in several countries, with respect to the control room, was conducted by the International Atomic Energy Agency (IAEA). Human Factors was considered in a much broader sense and a chapter 18 was included in the Final Safety Analysis Report (FSAR) of the nuclear power plants, addressing Human Factors engineering (HFE) issues [10]. However, the Human Factors by this time of TMI accident was mistaken understood just as the individual factors, it means, the individual issues of the workers. Few years later, in the 1986, the Chernobyl accident, Human Factors issues was complemented by the concepts of the organizational factors, especially connected to the safety – and operational – culture of the Soviet Union industries [11]. After this disaster, a solid path for the understanding started to be built, fetching the systemic understanding that the individual, organizational, environmental and technological factors, as well as their interactions, form an inseparable set that forms the so-called Human Factors.

Bringing a balance and more consolidated perspective, [12] presents that Human Factors deal with issues related to humans, their behavior and the physical aspect of the environment in which they work. And in this context, ergonomics is an inter-disciplinary research field that focuses on improving the functioning of the human-technology interaction about safety, specially showing the difference between WAI (Work-As-Imagined) and WAD (Work-As-Done). This is accomplished by considering the strengths and weaknesses of human performance, which in the FRAM methodology can be properly addressed in the resonance of the function's couplings. The goal of the ergonomics is to achieve the best possible match between products and users, in the context of the task to be performed. The ergonomics incorporation in the system design, interfaces and equipment offers a lot of opportunities for improvements regarding system effectiveness, efficiency, reliability and safety [13]. And, in fact, analyzing all the discussed concepts of Human Factors, ergonomics and human performance, under a more comprehensive systemic view of the modern complex socio-technical systems, such as a drilling unit of an offshore oil rig, Human Factors emerges as the main issue of scientific factors about human characteristics, covering biomedical, psychological and psychosocial considerations, including principles and applications in the personnel selection areas, training, aid tools for job performance and human performance evaluation.

Based in all of that evolution and principles, the current understanding of Human Factors is a comprehensive and widely understanding of all the factors that can have influence in the human performance during their work, and can be originated from inside, outside or even is part of the individual characteristic of a person. For IOGP [14], Human Factors are simply those things that can influence what people do. They may include factors relating to the job people do (e.g., time available or control panel design) personnel factors (e.g., fatigue, capability) and organizational factors (roles, manning levels). The idea that during the events leading up to accidents, people are acting in a way that makes sense to them at the time. All their knowledge, training, experience, organizational culture, and input from the environment combine to influence the decisions made and the actions taken. In this way, Human Factors is not simply "what the human being does", or "the mistakes made by the worker"; it is much more than that and requires a much greater understanding than simply blaming the human being for doing something wrong. Human Factors, in fact, is a philosophy of comprehension, from human perspective, where it is necessary to understand the interactions that happen in a sociotechnical system, involving all the technological, environmental, organizational, and individual elements of these. Thus, in a labor context, Human Factors are the set of all factors that can influence human performance in their work activities, being technological, environmental, organizational and individual, as well as the interaction between these and other factors that may arise. In the Figure 1 is presented a representation of this set, representing the current understanding of Human Factors.

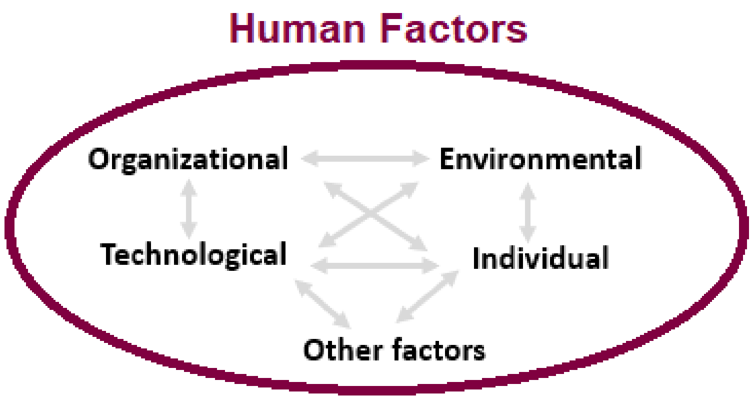

Figure 1: Human Factors representation.

Source: The authors, 2020.

As presented by this set, Human Factors are not a singular issue; it is a set of other factors that are present in the real work scenarios and have influence over the performance of the workers. The light grey doubled arrows show that all factors interact which each other, continuously. In this principle, Human Factors cannot be addressed or interpreted as only the individual factors, which is a quite common – and mistaken – understanding. Human Factors is far beyond that and is in fact all things that, one way or another, alter the workers performance in a labor context. And in most cases, the alteration in the performance, the variability of workers' performance, is something positive, which gets the job done. Thus, comprehend Human Factors is not a way (or “the way”) to avoid accidents, but a way to improve performance, which consequently reduces accidents and enhance production. And together and integrated with the evolution of Human Factors approach, there was also an integrated and inseparable evolution of workplaces, especially due to the technological evolution of machines, devices, and systems. As a result, and part of this evolution, the modern complex sociotechnical systems emerge, where through technology, workplaces are locals where there is intense interaction between workers, machines, environments, systems, and processes.

The sociotechnical systems behaving (interaction between social and technical elements with organizational and environmental issues) is heavily dependent on interactions within and between system components [15], independently of the occupation area, being able to characterize operating room (OR), pediatric intensive-care unit (PICU), as well as refineries or offshore oil platforms . There are different elements, different characteristics between them, but they certainly characterize complex sociotechnical systems with his own particularities. In this context, [16] postulates that safety may be seen as an emerging property of sociotechnical work, based on the natural interaction between Human Factors and the complex sociotechnical systems, and it is necessary an appropriate methodology to evidence these specific characteristics of this interaction. Seeking for un adequate answer for this, the FRAM (Functional Resonance Analysis Method) was found to be a valuable methodology for describing sociotechnical system and Human Factors interactions, based on a strong grounding in empirical studies and themes of “making work visible,” symmetry between human and nonhuman, and work as activity. Indeed, FRAM supports describing the dynamic interactions in sociotechnical systems from the perspective of normal performance variability that is necessary to understand how the real work is performed [17].

3 The Functional Resonance Analysis Method (FRAM)

The Functional Resonance Analysis Method (FRAM) is a methodology to analyze and describe the nature of workaday activities. Due this methodological structure, it can analyze past events of complex system, such as an accident investigation, as well as possible future events, as the Human Factors recognition and analysis of activities in a offshore drilling rig. For a professional who has never seen the graphical representation of a FRAM model, this methodology may seem relatively complex, which it is not. In fact, the analysis promoted by this methodology is not an algorithmic process, but rather the gradual development of a mutual understanding among a team of professionals working as a team. This methodology is based on four principles [18]:

1) Equivalence of failures and successes. Failures and successes come from the same origin, i.e. everyday work variability. This latter allows both things go right, working as they should, and things go wrong.

2) Principle of approximate adjustments. People as individuals or as a group and organizations adjust their everyday performance to match the partly intractable and underspecified working conditions of the large-scale socio-technical systems.

3) Principle of emergence. It is not possible to identify the causes of every specific safety event. Many events appear to be emergent rather than resultant from a specific combination of fixed conditions. Some events emerge due to combination of time and space conditions, which could be transient, not leaving any traces.

4) Functional resonance. The function resonance represents the detectable signal emerging from the unintended interaction of the everyday variability of multiple signals. This resonance is not completely stochastic, because the signals variability is not completely random, but it is subject to certain regularities, i.e. recognizable short-cuts, or heuristic, that characterizes different types of functions.

To build a FRAM model, it is necessary to follow four steps, which is the structure of the FRAM and begin with the identification of the functions. It means, the first step is the identification and the description of the functions, which can be human, technological or organizational, depends on its natures in the system, seeking to describe in detail how a task is done as a real everyday activity, rather than to describe it as an overall task or procedure. Analyzing this functions and its coupling with other functions, it is possible to see that is a valid representation of the real scenario where the work happens, which is an adequate way of Human Factors recognition, once those functions match with the n factors of the Human Factors characterization: organizational, individual, technological and environmental. The similarities are clear, although the words may appear different, which is the case of the individual factors, which corresponds to the human functions on the FRAM, and the technological and environmental factors, which merge into technological functions of the FRAM.

The graphic representation of a function is a hexagon, where there is, basically, one output and five inputs for each potential function. Each vertex of this hexagon is, in fact, the determination of one of the six aspects of the FRAM methodology function: Time, Control, Output, Resource, Precondition and Input. It is important to notice that the capital letters, begging each aspect observed, marks its difference from an ordinary input or output of a simple flow chart; they are the aspects that form the FRAM model and determined by its methodology as the connections between functions. In the Figure 2 is presented a representation of a function, which represents the activities being analyzed.

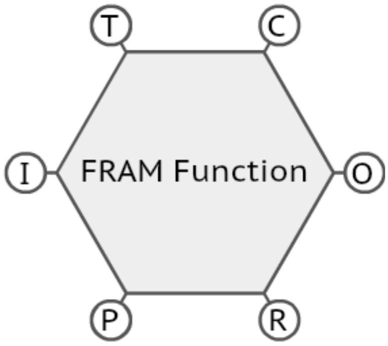

Figure 2: The graphic representation of a FRAM Function.

Source: FMV® software, 2020.

The FRAM modeling can be done manually, using drawn hexagons by hand or by graphic programs. But in addition to these solutions, there is also the FMV® software (FRAM Model Visualizer) [19], which allows a user to build and edit a FRAM mode and to visualize it in a unique software, dedicated for this purpose. It is important to emphasis that a FRAM model is the graphic representation of the real work done, considering all the interactions of the workplace. In a FRAM model there is no a priori order or sequence of the functions. The model consists of a set of function descriptions, based on a structured methodology.

4 Human Factors Approach to Process Safety using FRAM

The first step to develop a Human Factors approach and the FRAM model related to that is the understanding of the real work done. In this study, the activities chosen to be analyzed where the ones related to the daily routine of the Production Operators (PO) of an FPSO (Floating, Production, Storage and Offloading) unit. Also, the FRAM provides a method to describe a sociotechnical system in terms of its functions and the interactions between these, to analyze where performance variability may arise and spread throughout a system, and how the system may adapt to keep performance within the required parameters [16].

4.1 Understanding the FPSO Production Area

A FPSO unit is a special type of dedicated vessel used by the offshore oil and gas industry for the production and processing of hydrocarbons, as well as the storage of oil. They are projected to receive hydrocarbons – crude oil and natural gas – produced by itself or from nearby platforms or subsea structures, process these hydrocarbons, keeping the oil inside of its tanks and consuming the natural gas produced [20]. This gas is used for gas-lifting, production of electrical energy, heating, and pressure equalization; the surplus is flared. In the other hand, the stored oil, after being treated, analyzed, and framed, is transferred to another type of vessel, the FSO (Floating, Storage and Offloading), relieving the FPSO tanks to continuously receive the oil produced. On example of FPSO is presented in the Figure 3 [21].

Figure 3: Example of an FPSO, Campos Basin, Brazil.

Source: França, 2014.

The location chosen for analysis of this study is precisely the area of oil production of the FPSO, where there is intense interaction between OPs and the systems that form their work environment. Analyzing this work, it is clear that is a complex socio-technical system, where there is intense and complex interaction between workers, systems, equipment, procedures and other elements. The Human Factors approach of this complex socio-technical system is not limited to the human, that is, it not only analyzes the individual aspects, but also the organizational, technological, and environmental aspects.

4.2 The FRAM of the FPSO's Production Area

Based on the on board interviews, on board observations, process safety experts guidance and FRAM specialists support, a FRAM model was build, considering the Humans Factors, on board, that are crucial for Process Safety and that are present in the daily routines of PO. In this sense, to promote safety and effectively avoid a loss of containment, it is necessary to understand the complex socio-technical system where it is inserted. The current process plants, as the FPSO production area studied in this research, are complex socio-technical systems, where there is intense interaction between people, systems and relationships, in an environment of extremely high technological development, with risks that keep up this scale. The FRAM model develop represents the real work done by the PO, in their daily routines, considering their technical skills required for the job, as well as the non-technical skills, tacitly developed in their workplaces, in the cognitive and social dimensions. This FRAM model is presented in the Figure 4.

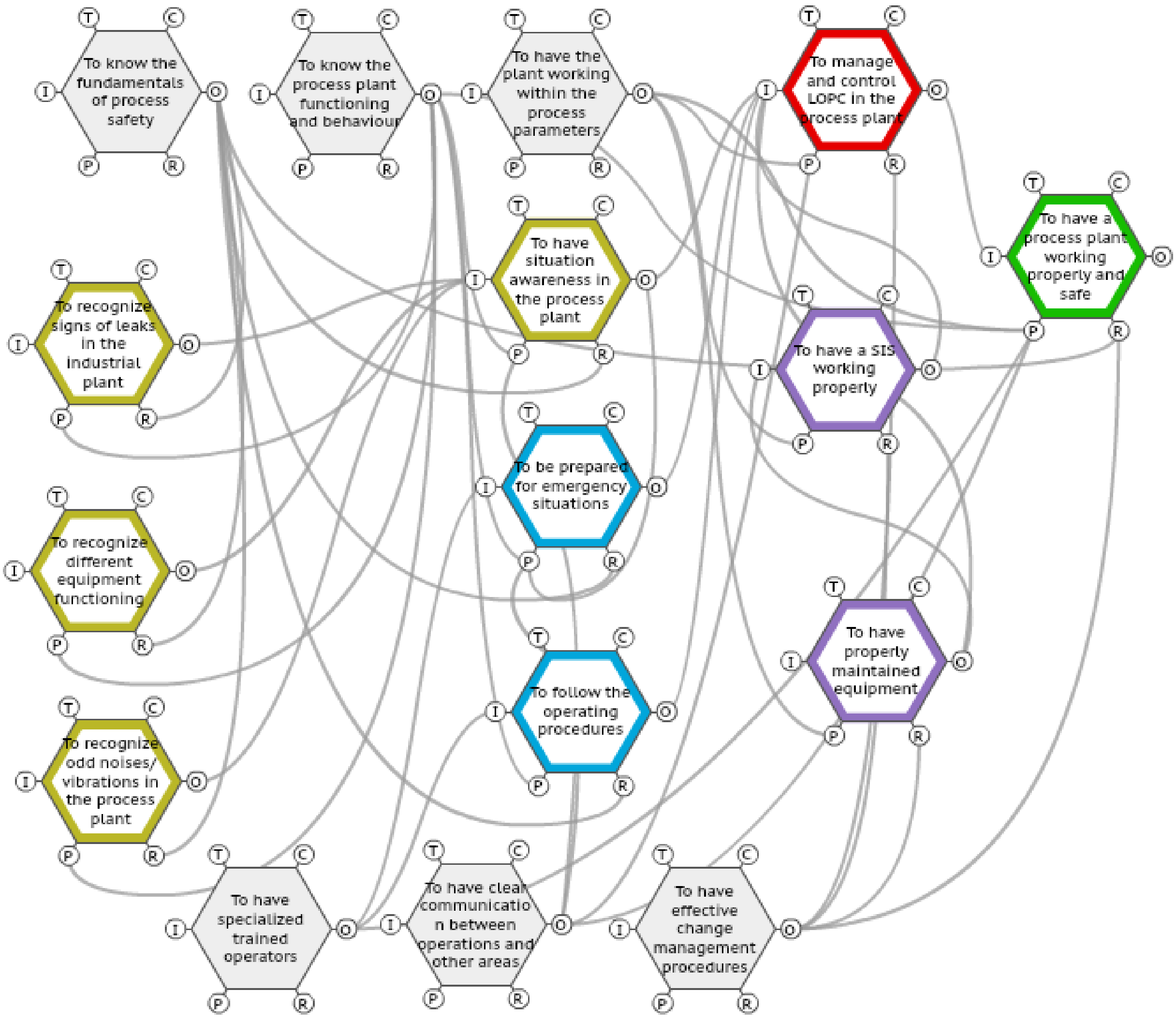

Figure 4: The FRAM model for FPSO Operations.

Source: The authors, 2020.

Analyzing this model, it is possible to see how interactions exits between the POs and the system where they are insert. The offshore work, quite different from onshore, and has elements of process safety, in preventive and mitigating barriers, critical to safety on board [1]. In this aspect, some characteristics of this work, in a complex socio-technical system, considering the process safety discipline, are highlighted, namely:

- The remoteness from the shore and the support infra-structure which are used to onshore;
- The rough weather, the unpredictability of environmental loads and impacts;

- The potential energy which can be released in the event of loss of containment;
- The impression of technical complexity and size, and possible distrust in the industry's ability to manage such complex systems variabilities in terms of accidents offshore, as they are perceived through the influence of the media;
- The gradual and continuous increase in the interactions and complexities of the work environment, characterizing the so-called complex socio-technical systems;
- The comprehension of the Human Factors, that is, all those factors that influence the performance of the worker in his workplace, being of an individual, environmental, technological, and organizational nature.

The Background functions are also part of the whole complex socio technical system. These functions are responsible for key Resources & Preconditions for the system functioning and, consequently, control and management of LOPC for process safety.

4.3 Non-Technical Skills are part of Process Safety

Analyzing an extract of the full FRAM model, it is possible to verify the importance of Non-Technical Skills (NTS) present in the daily routine of the POs, which not only is parts of their routine tasks, but also is present in non-planned and emergency situations, reflecting the POs the preparedness of these operators. Non-technical skills are the cognitive and social skills that complement the worker technical skills. They are not new or mysterious skills but are essentially what the best practitioners do in order to achieve consistently high performance and what the most professionals do in a productive day without accidents [22]. This extract of the full FRAM model is presented in the Figure 5.

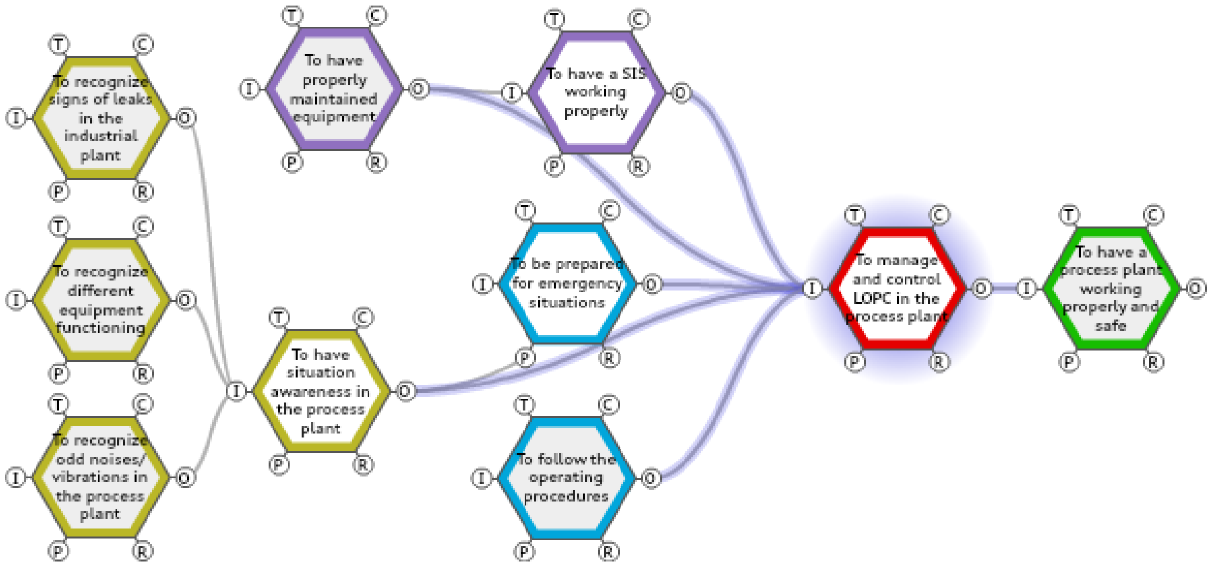

Figure 5: Extract of the FRAM model, highlighting Non-Technical Skills.

Source: The authors, 2020.

The Non-Technical Skills are important for safe and efficient performance in a range of high-risk work settings from industry, health care, military, and emergency services, not only being observed in the O&G industry, as this research discovery. These NTS provides a set of established constructs and a common vocabulary for learning about the important behaviors that influence safe and efficient task execution, being known as situation awareness, decision-making, communication, teamwork, and leadership. Others NTS can be considered in the any study of this area, but can be considered controversy, as managing stress or coping with fatigue [22]. Notice, in the extract of the full FRAM model, that the interactions of workers individual abilities and non-technical skills resonates through the system are directly responsible for the manage and control of LOPC, in the function “To manage and control LOPC in the process plant”. Consequently, through the complex socio technical system functioning and its resonance, the individuals dynamically promotes the properly working and safe of all system, merging and using dynamically their technical and non-technical skills.

5 Conclusion

The analyzes, observations, interviews and considerations promoted by this research enables to perceive that a LOPC can be effectively prevented by an operator, using their perception, awareness and abilities. The Human Factors interactions present is this complex socio technical system are the elements responsible for the productivity and safety, as reflected in the FRAM model built, based on the contribution of FPSO’s operators, process safety experts and FRAM specialists. This methodology showed Human Factors aspects that are effectives barriers for a LOPC, upholding that a wider comprehension of Human Factors is directly linked with Process Safety. Also, implementing a wider perspective in the Process Safety through a Human Factors approach promotes the productive and safe execution of the work in both normal and critical operations situations, and identifies the impact of human variability, considering NTS, in the execution of daily tasks. It shows that worker’s responses can properly deal with complex system demands both in normal situations and in emergencies, in any part of the process. And based on the theories and empirical studies related to systems theory, as well as the evolution of complex sociotechnical systems, it is noted that among the various complex systems, the Humans themselves are the most complex system of all. In this sense, and considering the findings of this research, especially the ones related to the NTS that promotes the resilience of the system and a dynamic barrier for LOPC, the workers are the solution, not the problem, being active elements and protagonists in the process safety, as well as in the productivity of the whole process plant.

6 References

[1] O. J. Tveit, “Safety issues on offshore process installations. An overview,” *J. Loss Prev. Process Ind.*, vol. 7, no. 4, pp. 267–272, 1994.

[2] R. Ogorkiewicz, *Tanks: 100 years of evolution*, First Edit. London: Osprey Publishing, 2015.

[3] S. J. Guastello, *Human Factors Engineering and Ergonomics*, 2nd Ed. Routledge, 2013.

[4] B. A. Turner and N. F. Pidgeon, *Man-Made Disasters*, Second Edi. Butterworth-Heinemann, 1997.

[5] A. Noroozi, N. Khakzad, F. Khan, S. Mackinnon, and R. Abbassi, "The role of human error in risk analysis : Application to pre- and post-maintenance procedures of process facilities," *Reliab. Eng. Syst. Saf.*, vol. 119, pp. 251–258, 2013.

[6] E. Akyuz and M. Celik, "A methodological extension to human reliability analysis for cargo tank cleaning operation on board chemical tanker ships," *Saf. Sci.*, vol. 75, pp. 146–155, 2015.

[7] P. Skalle, A. Aamodt, and K. Laumann, "Integrating human related errors with technical errors to determine causes behind offshore accidents," *Saf. Sci.*, vol. 63, pp. 179–190, 2014.

[8] L. J. Bellamy, T. A. W. Geyer, and J. Wilkinson, "Development of a functional model which integrates human factors, safety management systems and wider organisational issues," *Saf. Sci.*, vol. 46, no. 3, pp. 461–492, 2008.

[9] E. Hollnagel, "Human factors / ergonomics as a systems discipline ? ' The human use of human beings ' revisited," *Appl. Ergon.*, vol. 45, no. 1, pp. 40–44, 2014.

[10] I. Luquetti dos Santos, C. Grecco, A. Mol, and P. V. Carvalho, "The use of questionnaire and virtual reality in the verification of the human factors issues in the design of nuclear control desk," *Int. J. Ind. Ergon.*, vol. 39, pp. 159–166, 2009.

[11] A. Labib, "Learning (and unlearning) from failures: 30 years on from Bhopal to Fukushima an analysis through reliability engineering techniques," *Process Saf. Environ. Prot.*, vol. 97, pp. 80–90, 2015.

[12] I. J. A. Luquetti dos Santos, M. S. Farias, F. T. Ferraz, A. N. Haddad, and S. Hecksher, "Human factors applied to alarm panel modernization of nuclear control room," *J. Loss Prev. Process Ind.*, vol. 26, no. 6, pp. 1308–1320, 2013.

[13] J. M. O'hara, W. S. Brown, J. J. Persensky, and P. M. Lewis, *Human-System Interface Design Review Guidelines*. 2002.

[14] IOGP, "Demystifying Human Factors : Building confidence in human factors investigation understand facilitate," 2018.

[15] A. R. Wooldridge *et al.*, "Complexity of the pediatric trauma care process: implications for multi-level awareness," *Cogn. Technol. Work*, vol. 21, no. 3, pp. 397–416, 2019.

[16] L. De Vries, “Work as Done? Understanding the Practice of Sociotechnical Work in the Maritime Domain,” *J. Cogn. Eng. Decis. Mak.*, vol. 11, no. 3, pp. 270–295, 2017.

[17] Z. Zheng, J. Tian, and T. Zhao, “Refining operation guidelines with model-checking-aided FRAM to improve manufacturing processes: a case study for aeroengine blade forging,” *Cogn. Technol. Work*, vol. 18, no. 4, pp. 777–791, 2016.

[18] C. Nemeth, “Erik Hollnagel: FRAM: The functional resonance analysis method, modeling complex socio-technical systems,” *Cogn. Technol. Work*, 2013.

[19] R. Hill, “FMV® - FRAM Model Visualizer.” Zerprize, 2018.

[20] T. Abramowski, “Initial Design Considerations for FPSO Vessel,” *Marit. Univ. Szczecin*, vol. 17, no. January 2006, pp. 9–21, 2006.

[21] J. França, “Alocação de Fatores Humanos no Gerenciamento de Riscos de Sistemas Complexos Offshore,” UFRJ, 2014.

[22] R. Flin, P. O’ Connor, and M. Crichton, *Safety at the Sharp End: A Guide to Non-Technical Skills*. London, UK: Taylor & Francis Group, CRC Press, 2016.