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Mapping the Causality of Workplace Accidents: a Hybrid Approach HFACS-Graph

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Abstract

Workplace accidents continue to pose a significant challenge, resulting in severe repercussions for employees and companies. A comprehensive analysis of these incidents is essential for understanding their underlying causes and preventing their recurrence. Previous studies have shown that Human errors are one of the major contributors to accidents. Human errors have to be addressed to improve safety and prevent accidents. Human Factors Analysis and Classification System (HFACS) has been developed as an analytical framework for investigating the role of human and organisational errors in company accidents. In contrast to traditional methods, HFACS adopts a more comprehensive perspective on accidents, recognising that they are not simply caused by human error but rather by a sequence of events occurring at various levels. It offers an effective approach to enhancing workplace health, safety, and well-being. Although HFACS is a useful tool, it has one major limitation: it is qualitative and cannot clearly establish causal links between the various factors identified. To overcome this shortcoming, we propose a hybrid approach combining HFACS with an adjacency matrix. The aim is to create an HFACS Graph (HFACS-Gr) that illustrates the causal relationships between factors and helps to identify the critical paths that contributed to an accident. This method aims to provide a more in-depth and structured understanding of the causal chains leading to accidents. The article presents an investigation of a work-related accident at an Algerian company utilising HFACS-Gr. The analysis uncovers the combination of human, organisational, and environmental deficiencies that led to the accident's occurrence.

Keywords: *Investigation, HFACS, Adjacency Matrix, Graph Theory.*

1. INTRODUCTION

Technological progress has led to radical transformations in all professional domains with many benefits (Wrigley. 2017; Xu et al., 2018). Unfortunately, they are tainted by the occurrence of Occupational Risks (Svertoka et al., 2021).

Occupational risks, which cover both accidents at work and occupational illnesses, are events that occur as a result of work. They are an integral part of working life and a major concern for employers worldwide, as they have tragic consequences.

To manage and prevent the consequences of occupational risks, it is essential to identify and understand the main causes. The literature has shown that several factors contribute to their occurrence (Wasungu. Wognin, 2018). However, research in the field has prioritised the human and organisational aspects (Swuste et al. 2020; Niciejewska et al. 2021).

In the workplace, risk prevention is based essentially on investigating occupational risks. This is the most effective method, and also the most cited by researchers in the field (Jacinto

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et al, 2011; Comberti et al, 2018;). First, is because it makes it possible to identify the causes by asking why and how the events occurred. Secondly, the investigation of occupational risks enables preventive and corrective measures to be recommended (Morrish. 2017).

There are many keys to the success of the investigation process. In addition to the actors' effective involvement and the investigators' competence, the investigation depends on the use of appropriate models known as "accident causation models". The specialised literature on this subject is extremely rich in terms of studies devoted to accident causation models (Woolley et al. 2019; Fu et al. 2020). These models provide a theoretical lens through which the dynamic interaction between factors contributing to accident occurrence is highlighted. These models' history can be traced back to the 1920s when they underwent several classifications (Zaranezhad et al. 2019, Fu et al. 2020).

Among those cited in the literature, we have retained the HFACS (Human Factors Analysis and Classification System) model. This model is known for its ability to identify root causes of accidents, its adaptability to various sectors, its focus on prevention, its international recognition, and its use for both retrospective and prospective analysis of incidents (Hulme et al. 2019, Xia et al.2021). This makes it a valuable model for improving health and safety in many areas through human, technical and organisational corrective practices (Wang et al. 2018).

In Algeria, according to data from the National Social Security Fund (CNAS), the total number of occupational accidents recorded was 47,555 in 2018, 49,782 in 2019, 36,275 in 2020 and 42,032 in 2021. Consequently, Algerian companies present an environment exposed to various risks that menace workers' lives and lead to work accidents with tragic consequences and significant losses. Preventing these accidents is important to reduce their consequences and avoid their recurrence.

In this context, the HFACS model, the adjacency matrix, and the graph theory have been employed to investigate and prioritise the causes of an accident at an Algerian company. This work aims to elucidate why an organisation with a reliable safety system in place consistently fails to prevent accidents. Not that this investigative tool has never been applied in the Algerian context.

The study is then structured as follows: in the next section (section two), we present the literature review on the HAFACS method, section three is devoted to the proposed methodology, and section four focuses on the application of this proposed model to the investigation of an accident that took place in an Algerian company, intending to identify the active and latent causes behind this accident through the use of HFACS-Gr. Finally, the last section is reserved for discussing the results obtained and a conclusion.

2. LITERATURE REVIEW ON THE HAFACS METHOD

Based on Reason's (1990) concept of latent and active failures, HFACS considers that errors committed by front-line operators are active errors resulting from many latent causes Shappell & Wiegmann (2001).

Active failures are combinations of inappropriate actions committed by operators, while latent conditions concern the different levels of the organisation. The latent causes are mainly organisational and managerial dysfunctions, as well as deficiencies in the safety culture.

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HFACS provides a comprehensive analytical framework for identifying the sources of human error (Hulme et al. 2019; Jalali et al. 2023).

The HFACS model encompasses 19 causal categories divided into four levels of human failures, with at least 69 sub-categories. The four HFACS levels, described in Figure 1, represent organisational influences, unsafe supervision, preconditions for unsafe acts, and unsafe acts (Yoon et al., 2017).

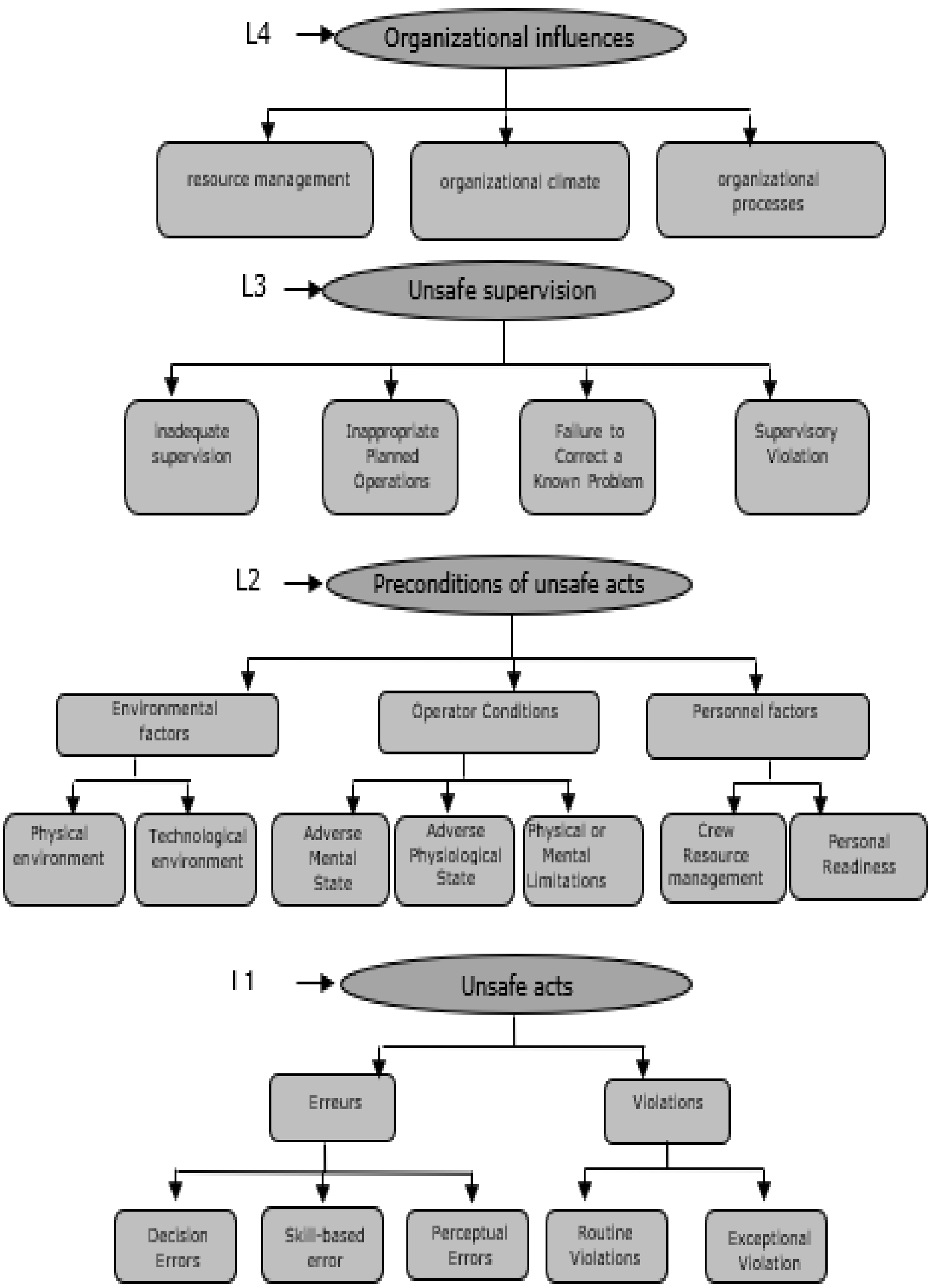

Figure 1: HFACS S framework (Wiegmann and Shappell, 2003)

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In this context, Salmon et al., (2012) confirm that given its categorical nature, which is well adapted to multiple case studies, HFACS is one of the most promising methods for analysing the structure of human factors, compared with Accimap and STAMP.

Refer to Ergai et al. (2016), the HFACS model provides a detailed classification of the different failure levels and precisely defines the sub-categories of each level, making it easy to use. Theoretically, several successive failures at various levels are necessary for an undesirable event to occur. However, correcting one of these failures is sufficient to prevent the undesirable event from occurring (Shappell et Wiegmann, 2004)

Similarly, Alexander (2019) evaluated 15 Human Reliability Analysis (HRA) methods and concluded that HFACS is the most appropriate for analysing human error in space operations, companies, and organisations. According to Aydin et al. (2022), HFACS is one of the most relevant frameworks for studying human factors, organisational failures, and their interactions leading to accidents.

Furthermore, HFACS is one of the most widely used analytical methods for examining and classifying the causal factors of accidents and incidents in various fields. Indeed several research studies, in the last decade, confirm that HFACS was not only successfully applied in the aviation (Li et al; 2022), but also in the mining industry (Kandemir., 2021), construction industry (Ye et al, 2018), maritim accident (Qiao et al., 2020), railways (Li et al, 2019), oil and gas industry (Theophilus et al, 2017), healthcare sector (ElBardissi et al, 2007) and Biopharmaceutical Manufacturing (Cohen et al, 2018).

However, despite its wide range of applications and the advantages it offers, the identification of human factors at different levels within the HFACS model would, in general, involve lots of issues associated with human judgment and feelings, which leads to subjectivity and imprecision of the results to a certain extent. In addition, HFACS provides a framework for qualitative analysis of the factors contributing to accidents but does not allow quantitative analysis of the causal links between these different factors. To improve its performance, quantitative methods need to be incorporated into the model (Ma et al., 2022).

Neural networks have also been used to predict the unsafe acts (Level 1 errors) from preconditions of unsafe acts (Level 2 errors) (Harris and Li, 2019) and even classify HFACS nanocodes from text data (Neuhaus et al., 2018). In the same context, several works have proposed hybrid HFACS (Zarei, 2019; Zhang et al., 2019).

In the following sections, we describe each of the four levels (and their sub-categories) of the original HFACS framework as presented by Shappell and Wiegmann (2004). We also introduce more recent modifications to the HFACS framework that we propose to refine the study.

3. MATERIAL AND METHODOLOGY

Given the limitations of the HFACS method, we propose a hybrid approach to refine the analysis and prioritise the generic causes of the accident.

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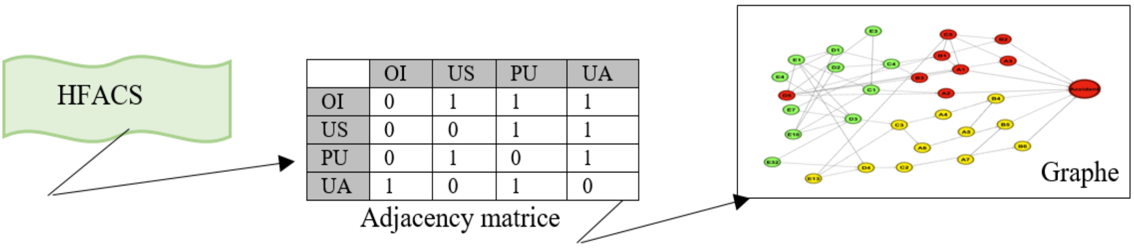

	OI	US	PU	UA
OI	0	1	1	1
US	0	0	1	1
PU	0	1	0	1
UA	1	0	1	0

Figure 2: HFACS-Gr accident investigation approch

The method simply combines the HFACS, the adjacency matrix, and the graph theory (GR) for modelling human error. The model, named the HFACS–Gr, was introduced as a hybrid accident analysis approach. The approach incorporates 03 steps given in Figure 2, and the explanation of each step is as follows:

3.1. HFACS

3.1.1. Level 1: Unsafe Acts (UA)

The unsafe acts are termed active failures, which are classified into two categories: errors and violations (Reason, 1990). The unsafe acts are distinguished from latent causes by their nearness to the accident and the relatively short time it takes for their adverse effects to manifest themselves. In general, errors represent the mental or physical activities of individuals. Violations are related to departures from organisational procedures, rules, and regulations. Both errors and violations often represent the cognitive shortcuts of human decision-makers (Simon, 1990). Errors are categorised into decision errors (related to lack of knowledge, experience, or information), skill-based errors (related to the performance of routine activities), and perceptual errors related from degraded or impaired sensory inputs and/or loss of situational awareness. Violation can be either routine (habitual) or exceptional (one-time departures) (Bickley, & Torgler., 2021).

3.1.2. Level 2: Preconditions for Unsafe Acts (PU)

Focusing solely on unsafe acts is insufficient. Investigators must examine the underlying reasons for these acts. Preconditions for unsafe acts reflect the latent conditions most directly linked to their occurrence, offering the best predictive power. This level includes operator conditions, environmental factors, and personnel factors. It encompasses adverse mental and physiological states, physical/mental limitations, physical and technological environment, as well as communication, coordination, planning, and personnel preparation. (Baldissone et al., 2019; Harris and Li, 2019)

3.1.3. Level 3: Unsafe Supervision (US)

Reason (1990) traced the causal chain of events back to the supervisory control chain**.** The third level of HFACS, unsafe supervision, is broken down into inadequate supervision (related to the lack of adequate guidance, leadership, and training opportunities for front-line workers), planned inappropriate operations (related to the management and quality of training for front-line workers), inappropriate planned operations (relating to the management and allocation of work, including risk management and operational rhythm), failure to correct known problems and violations of rules, regulations, and standard operating procedures) (Shappell and Wiegmann, 2004)

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3.1.4. Level 4: Organisational Influences (OI)

According to Shappell and Wiegmann (2004), organisational influences comprise three categories: resource management, organisational climate, and organisational processes. Resource management pertains to the allocation and upkeep of an organisation's resources, encompassing personnel, finances, equipment, and facilities. Organisational climate refers to the broad range of organisational variables that impact employee performance and satisfaction, such as culture, command structure, and policies. Organisational processes relate to the procedures and methods that govern the business's day-to-day operations and enable managerial oversight. These include production quotas, incentive schemes, schedules, standards, work instructions, safety programs, and measuring and reviewing key performance indicators.

3.2. Adjacency matrix and graph theory

Adjacency matrix representations have been used for a long time in mathematics and graph theory (Zheng et al., 2023). Their implementation in the field of information visualisation, communication, and accident-cause prevention is proving interesting (Bousfot et al., 2023).

The adjacency matrix A (n×n) is a matrix representation exactly equivalent to the HFACS model. The rows and columns in this matrix represent the causality factors for each HFACS level. This (n×n) matrice is binary, i.e. :

Aij = 1, if there is a link between the nodes i et j.

0, otherwise.

The graph is an effective mathematical tool for representing the links between the causal factors of the accident, where the nodes represent the causal factors and the arcs represent the relationships between these causal factors. Graph analysis can reveal alternative paths or modifications that could optimise workplace safety.

4. HFACS-Gr ACCIDENT INVESTIGATION

4.1. Data

4.1.1. Overview of the accident

In an Algerian company operating in the hydrocarbons sector, a lifting operation carried out by a subcontractor took place at around 7.15 pm (night shift) to close (positive insulation) the natural gas inlet to a two-phase separator using a 24-inch solid flange. A pivoting support tube attached the flange to the separator's tank structure. This device allows easy manoeuvring and facilitates adjustment of the 24-inch flange. Once the operation had started, the load became detached, and the clamp struck an operator, causing him to fall onto a hard object, resulting in a fatal head injury.

4.1.2. Circumstances of the accident

Activities started as planned with a lifting team for the day shift (from 06:00 to 18:00 daily). On 14 July 2020, the day of the isolation of the natural gas separator, the full flange of the gas inlet was opened again; it misaligned (misplaced) below its required level by a few millimeters. On 18 July 2020, a permit to work was completed and issued for the natural gas separator to carry out the mechanical (positive) desolation.

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On 19 July, at 6.30 pm, the permit to work was re-approved for the night shift, and all the managers signed i. At 19:00, the manager in charge of the scheduled shutdowns decided to use the crane to adjust the 24-inch full flange to obtain the correct alignment with the bolts holding the structure in place.

The work group comprised five (05) persons: the crane operator, the rigger, and three (03) mechanical technicians. At 7.15 pm, the mechanical technicians intended to close (positively isolate) the main entrance to the gas separator, which meant lifting the flange slightly to adjust it for proper alignment. The 24' flange is supported by a pivoting tube.

When they started to lift it, slinging it busy and putting away the lifting accessories (end of shift), the rigger (flag man) preferred to hang the sling on the support because he assumed it would be easy to adjust the flange. When the crane operator started lifting, the load was pulled with force, causing the flange to fall and the threaded stud to bend. As the flange fell, it struck the operator, who hit his head on a hard object, causing a fatal head injury.

The data collected on this accident is based on the report of the accident and the investigation carried out by the various parties involved, i.e. the company, the labour inspectorate, and the national social insurance fund. Using the cause tree approach, the company's investigation attributed the immediate cause of the accident to human error.

4.2. Results of the investigation

When applying the HFACS model to analyse a specific accident, it is essential to precisely define the accident scenario and identify all the conditions under which it occurred. Then, by organising safety meetings involving various experts, the levels and categories of the HFACS model are used to identify human failures at different levels, from active operator failures (level 1) to latent organisational failures (level 4) (Garrett and Teizer, 2009). In this study, the group of experts was made up of HSE supervisors, two Joint Health and Safety Committee JHSC members, the occupational doctor, and an HFACS animator.

As a first step, the main causes of accidents are identified and categorised according to the structure of the HFACS framework. This systematic approach establishes a solid basis for the subsequent analysis of causal relationships. The results of the accident investigation by HFACS are shown in Table 1.

- For UA, the most active errors were decision-making errors, skill-based errors, and routine violations. Exceptional violations were not identified in this study.
- The most common PU were physical environment factors, mental state unfavourable physical state, and mental limitations.
- US are related to inadequate supervision, inappropriate planned operations, failure to correct known problems, and violation of supervision.
- Finally, OI includes deficiency in the management of resources, lack of organisational climate, and lack of organisational process.

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Table 1: HFACS investigation

Level 1 : Unsafe Acts
UA_1 : Incorrect assessment of a dangerous situation
UA_2 : Incorrect execution of the task.
UA_3 : Error of judgement
UA_4 : Perception error
UA_5 : Violation of safety procedures ;
UA_6 : Machine maintenance carried out by non-specialist
UA_7 : Sling hooked on the support
UA_8 : Staff not involved in safety issues
Level 2: Preconditions for unsafe Acts
PU_1 : Potentially poor lighting conditions situation
PU_2 : Luk of arrangement of the workplace
PU_3 : Reduced physical capacity.
PU_4 : Mental limitations
PU_5 : Personal Readiness fatigue of the staff
PU_6 : lack of clear and effective communication between operators
PU_7 : Lack of safety meeting
$PU_{8\,:}$ Lack of coordination of team
Level 3: Unsafe Supervision
US_1 : lack of involvement of the supervisor control of the risky operation.
US_2 : Poor handling of work schedules and employee shift rotations.
US_3 : Deficiencies in training and awareness-raising for staff
US_4 : Inadequate supervision of lifting operations during the night shift.
US_5 : Lack of communication on hazards and potential risks to staff
US_6 : lack of risk identification in lifting operations
$US_{7\,:}$ Lack of checking that the load is properly slung by a supervisor before lifting
$US_{8\,:}$ Signing permis to work during the night shift for a team that worked the day shift without a break
Level 4: Organizational Influences
OI_1 : Inadequate allocation of resources planned shutdowns, with only the day shift.
OI_2 : A lack of human resources to carry out the work in several shifts.
OI_3 : Lack of safety culture, work permit was revalidated for the night shift by all the managers
OI_4 : Failure to adhere to procedures
OI_5 : lack of adequate training on lifting risks for all personnel involved in the accident
OI_6 : Deficiency of operation management plan
OI_7 : Lack of organisation
OI_8 : insuficient inspection

After that, an adjacency matrix of the accident is given in Table 2. The matrice has been elaborated by the experts retained in this work. It explores the effect of factors in the first column on factors in the first row.

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Table 2: adjacency matrice

	Organizational Influences (OI)								Unsafe Supervision (US)								Precondition for Unsafe acts (PUA)								Unsafe Acts (UA)							
	OI_1	OI_2	OI_3	OI_4	OI_5	OI_6	OI_7	OI_8	US_1	US_2	US_3	US_4	US_5	US_6	US_7	US_8	PU_1	PU_2	PU_3	PU_4	PU_5	PU_6	PU_7	PU_8	UA_1	UA_2	UA_3	UA_4	UA_5	UA_6	UA_7	UA_8
OI_1		1	1	1	0	1	1	1	0	1	0	0	0	0	0	1	0	0	1	1	1	0	0	0	0	1	0	0	1	0	0	0
OI_2	1		0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	0	0	1	0	0	0
OI_3	1	0		1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
OI_4	1	0	1		1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	0	0	1	1	1	1
OI_5	1	0	1	1		1	0	1	0	0	1	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1
OI_6	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
OI_7	1	1	0	1	1	1		1	0	1	0	1	1	0	0	1	0	1	1	1	1	1	1	1	0	1	0	0	1	1	0	1
OI_8	1	1	0	1	1	1	1		0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
US_1	0	0	1	1	0	1	0	0		0	1	0	1	1	1	0	0	0	0	0	0	1	1	1	0	0	1	1	1	0	1	0
US_2	1	1	1	1	0	1	1	0	0		0	0	0	0	0	0	0	0	1	1	1	0	0	1	0	0	0	0	1	1	1	0
$US3_1$	0	0	0	1	1	1	0	0	0	0		0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
$US4_1$	0	0	0	1	0	1	1	1	0	0	0		0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0
$US5_1$	0	0	0	1	1	1	1	1	0	0	0	0		0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0
US_6	0	0	0	1	1	1	0	0	0	0	1	0	0		1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
US_7	0	0	0	1	0	1	0	1	0	0	0	1	0	1		0	0	0	0	1	1	1	1	1	0	0	0	0	0	1	0	0
US_8	1	0	0	1	0	1	1	1	0	0	0	0	0	0	0		0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
PU_1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
PU_2	0	0	0	1	1	1	1	0	0	0	1	0	0	0	0	1	1		0	0	1	0	0	0	0	1	0	0	1	0	0	0
PU_3	1	1	0	1	1	1	1	0	0	1	0	0	0	0	0	1	0	0		1	1	0	0	0	1	0	0	0	0	0	0	0
PU_4	1	1	0	1	0	1	1	0	0	1	0	0	0	0	1	1	0	0	1		1	0	0	0	0	1	1	1	1	0	0	0
PU_5	1	1	0	1	0	1	1	0	0	1	0	0	0	0	1	0	0	1	1	1		1	0	0	0	1	1	1	0	0	0	0
PU_6	0	0	0	1	0	1	1	0	1	0	0	0	1	1	1	0	0	0	0	0	1		1	0	0	1	0	0	0	0	0	0
PU_7	0	0	0	1	0	1	1	0	1	0	1	1	1	0	1	0	0	0	0	0	1	1		0	1	1	0	0	0	0	0	1
PU_8	0	0	0	0	0	1	1	0	1	1	0	1	1	0	1	0	0	0	0	1	1	1	0		0	1	0	0	0	0	0	0
UA_1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0		1	0	0	1	1	1	0
UA_2	1	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1		1	1	1	1	1	1
UA_3	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	1		1	1	0	1	0
UA_4	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1		0	0	0	0
UA_5	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	1	1	0		1	1	1
UA_6	0	0	0	1	0	1	1	1	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	1		0	1
UA_7	0	0	0	1	1	1	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0		0
UA_8	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	0	

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An HFACS-Gr is generated from the adjacency matrice, as shown in Figure 3. This graph represents the four HFACS levels and the causal factors associated with each level. It can be used to provide a more refined analysis of the accident by measuring centrality values, modularity and relative importance of causal factors.

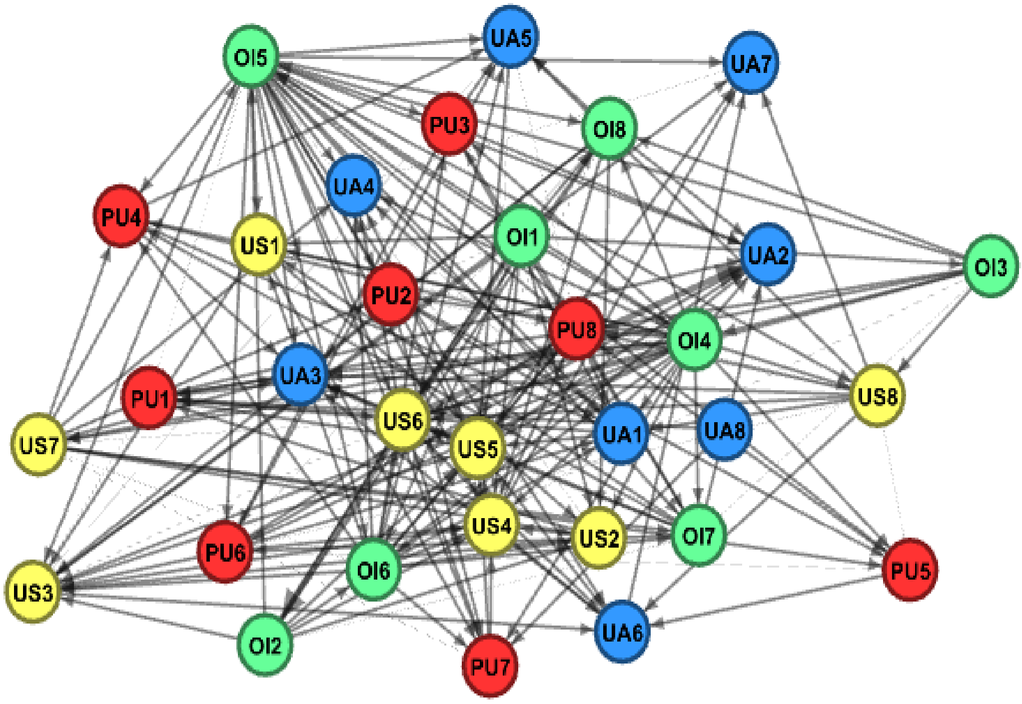

Figure 3: HFACS-Gr accident investigation

i. Centrality values of causal factors in accident analysis

We have retained three measures for centrality: Degree Centrality, Closeness Centrality, and Betweenness Centrality.

Degree centrality measures the number of connections a cause has with other causes in the network (see Figure 4). It is a powerful measure for identifying the most influential cause in a network. These causes can be considered as central or influential causes of accidents, as they are directly linked to many other causes. The largest nodes in the network are those with the greatest number of direct connections to other nodes.

Closeness Centrality (see Figure 5) measures assess the ability of a cause to reach other causes quickly in terms of the number of links.

Finely, Betweenness Centrality assesses the influence of a cause on the control of information circulating in the network (see Figure 6). The largest nodes act as critical channels for transmitting information between different groups of causes. These causes can be seen as important control points in the network of accident causes.

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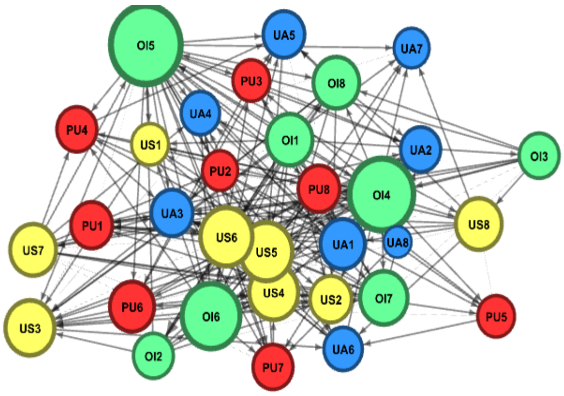

Figure 4: Degree centrality

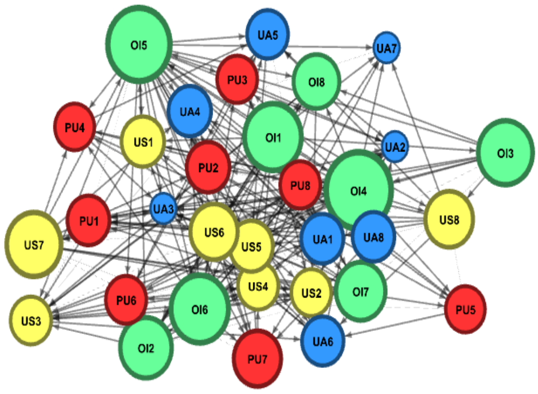

Figure 5: Closeness centrality

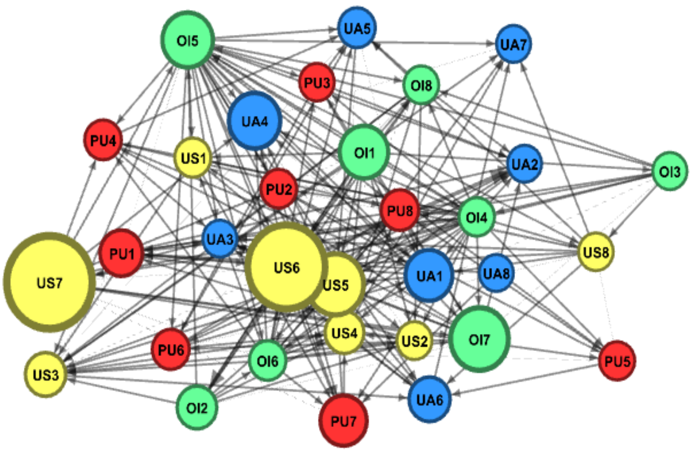

Figure 6: Betweenness Centrality

ii. Modularity value

This measure can be used to detect communities within the network of accident causes. The network can be divided into communities of causes that are strongly connected to each other and weakly connected to other groups. For this accident, the analysis identified four main communities (see Figure 7)

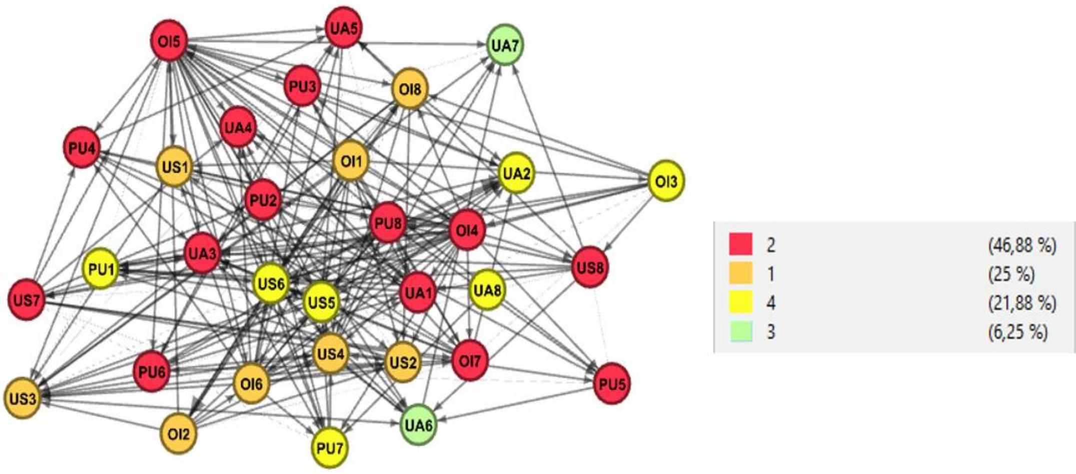

Figure 7: Modularity

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iii. Relative importance

This measure is used to assess the relative importance of the causes of accidents in a network based on the structure of the links between them. The result of this analysis is shown in Figure 8

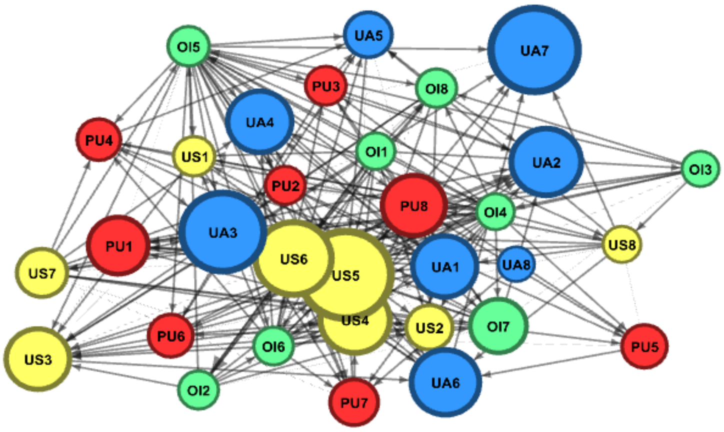

Figure 8: Relative importance

In a network of accident causes, the largest nodes represent the risk factors or causes that are most influential or most often involved in accidents.

5. DISCUSSION

A detailed analysis of the factors that led to the accident at the Algerian company was carried out to identify the root causes of the event.

Most causal factors have been identified at the level of unsafe acts, preconditions of unsafe acts, inadequate supervision, and organisational influences. As expected, the immediate causes can be traced back to latent causes, as mentioned in several studies (Kaptan et al., 2021; Jalali et al., 2023).

HFACS analysis (Tab 1) reveals that:

- For UA, decision errors are essentially due to the operator's inadequate reaction when carrying out the task. Perception errors are mainly due to unscheduled night work. Violations are linked to maintenance personnel's non-compliance with safety procedures. Exceptional violations were not identified in this study.
- Concerning PU, physical environment factors referred to potentially poor lighting conditions due to unscheduled night work and an unadapted workspace. Unfavourable mental states involve fatigue, insufficient staff training in safety and procedures, and a lack of clear and effective communication channels to inform staff of potential risks. Unfavourable physical state and mental limitations are due to the overtime workload and night work.
- In the US, inadequate supervision is linked to the lack of involvement of the supervisor in the preparation and control of risky operations, ineffective management of work schedules and staff rotation, and deficiencies in staff training and awareness. Inappropriate Planned

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Operations lead to inadequate supervision of lifting operations during the night shift. Failure to correct problems was identified in two cases: inadequate communication of risks to staff and deficiencies in identifying risks in lifting operations. Violation of supervision in this study was linked mainly to lack of control and violation of procedures.

- Relating to OI, deficiency in the management of resources refers to the inadequate allocation of resources (the same team works both the day and night shifts without a break). The organisational climate is characterised by a poor safety culture (all managers revalidated the work permit for the night shift). The organisational process is marked by a lack of supervisors' compliance with procedures, highlighting the need to improve emergency procedures and training. It is also affected by a lack of strategic guidelines, which points to a major need to review the necessary strategic guidelines.

HFACS-GR, as shown in Figure 3, represents the four levels of HFACS (OI, US, PU, UA), and it has the merit of addressing the limitation of the HFACS method. It illustrates the complex interconnections between the different levels of the HFACS model, showing how factors at different levels can influence each other in the causal chain of accidents and also shows the most influential causal factors.

The degree of centrality which identifies the central factors in the accident analysis in terms of connection. According to Figure 4, the Organisational Influences (OI): OI5, OI4, OI6, OI8, and OI1 have a dominant centrality, revealing that these factors significantly impacted the other factors in the causal chain. The figure also illustrates that Unsafe Supervisions (US): US3, US6, US5, and US4 appear to have a high centrality. This suggests that the US had a crucial role in the accident, interacting with many other factors. On the other hand, certain causes of pre-condition for unsafe acts (PU) and unsafe acts (UA) reveal a high centrality but, overall, less than those of the US and OI. The latter represents the consequences of organisational factors and pre-conditions.

Furthermore, Figure 5 represents the closeness centrality of the HFACS analysis. On average, a cause with a high proximity centrality has the shortest paths to all the other causes in the accident causal chain. The graph shows that OI: OI4, OI5, OI6, followed by US: US7 US8, represent the most critical paths in the accident causal chain. The PU: PU3 and PU8 highlight the environmental and personal factors that lead to unsafe acts. The UA: UA1, UA4, UA6, and UA8 are the most central at this level, representing key actions in the accident chain of events. The factors with the highest centrality (OI and US) are the targets requiring priority action for corrective and preventive measures. These graphs show numerous connections between the different levels, illustrating how organisational and supervisory failures can create conditions favourable to unsafe acts. This result is confirmed by several studies (Filho et al., 2017; Xie et al.2018; Hulme et al. 2019; Kaptan et al. 2021; Jalali et al. 2023).

For a more refined investigation, the betweenness centrality analysis (Figure 6) points to the elements which act as critical channels for the propagation of the cause of the accident between the different HFACS levels, thus offering the strategic intervention to optimise the system's overall safety. In the case of this accident, US: US7 and US6 appear to play a crucial role in linking the different HFACS levels. Kwasiborska et al. (2023) emphasize periodic training to organize raise awareness of the actions carried out during activities, which contributes to improving safety at workplace.

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In addition, the modularity analysis (see Figure 7) provides a unique view of the related structure of the factors causing the accident, highlighting groups of highly connected factors. Community "1" represents 40.62% of the network, indicating a high density of connections between the causes in this community.

Community "2" covers 25% of the network, followed by community "3" with 18.75% and community "4" with 15.62%. These percentages suggest an unequal distribution of accident causes, with some causes being strongly interconnected within large communities. In particular, community "1" includes OI causes: OI4, OI5, OI7, US causes: US7, US8, PU causes: PU2, PU3, PU4, PU5, PU6, PU8 and finally UA causes: UA4, UA5, underlining the importance of these factors in the accident causal chain. The structure of this community groups together the levels of classic HFACS, where safety problems tend to cluster together and require particular attention in terms of safety barriers.

The graph in Figure 8 illustrates the relative importance of the various factors in the accident causal chain. The causes: UA7, UA3, US6, US5 are very important in relative terms and are therefore the most active or critical factors. UA factors are very important, especially UA7 and UA3. In terms of supervision, US6 and US5 are significant. Some organisational factors (OI) are remarkably important, underlining their effect on the entire causal chain.

Furthermore, the study emphasized the existence of skill-based errors at various levels of the HFACS model. In this context, Wiegmann et Shappell (2005) had stated that this type of error is one of the primary contributing factors to accidents in all occupational workplaces.

HFACS-Gr presentation makes it possible to quickly target the most critical factors at each HFACS level, making it easier to prioritise interventions and make decisions to improve health and safety at work.

The HFACS-Gr model appears to be a useful tool for identifying all the important data on the latent causes that lead to the immediate causes (human error). The failures identified at all levels provide a relevant and ideal framework for corrective and preventive measures (technical, human, and organisational safety barriers), as well as palliative practices aimed at correcting work situations considered unsafe.

6. CONCLUSION

The HFACS model is based on the principle that accidents result from several causes. Its application made it possible to identify different categories of human, organisational, and environmental factors that contribute to the occurrence of accidents.

Detailed analysis of these factors using the HFACS model revealed several important elements. Unsafe acts highlighted violations and errors linked to the use of inadequate equipment, lack of compliance with procedures, and lack of staff training. Misperceptions and skills also impact behaviour in the workplace. Regarding the preconditions for unsafe acts, environmental factors are decisive in worsening the situation.

Night work and the space organisation created an environment favourable to accidents. Furthermore, inadequate supervision results from neglect on the part of the supervisors, a condition particularly linked to insecure supervision. Finally, organisational influences also contributed. An organisational climate that did not emphasise safety and a lack of resource management to train and raise awareness of hazards contributed to errors and violations.

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The use of HFACS-Gr has made it possible to illustrate cause-effect chains, helping to identify the factors causing the accident. By measuring the interactions between different causal factors at different HFACS levels (human, technological environment, physical environment), it is easier to identify causes and groups of causes. In addition, graph analysis can reveal critical paths where modifications and improvements could optimise workplace safety. Graphs provide a clear visual representation, making it easier to communicate the investigation results to all stakeholders.

Furthermore, HFACS-Gr illustrates how factors at higher levels (OI, US) influence those at lower levels (PU, UA). There is a cascade of influences from organisational influences to dangerous acts.

The analysis using HFACS-Gr clearly shows that inappropriate decisions taken at the highest level significantly and negatively impact staff and their behaviour at all levels. Indeed, strategic decision- failures have a detrimental effect on supervisory practices, affecting the pre-conditions for unsafe acts and, consequently, the actions of front-line operators.

References

1) Alexander, T. M. (2019). A case based human reliability assessment using HFACS for complex space operations. Journal of space safety engineering, 6(1), 53-59.

2) Aydin, M., Uğurlu, Ö., & Boran, M. (2022). Assessment of human error contribution to maritime pilot transfer operation under HFACS-PV and SLIM approach. Ocean Engineering, 266, 112830.

3) Baldissone, G., Comberti, L., Bosca, S., Mur`e, S., 2019. The analysis and management of unsafe acts and unsafe conditions. Data collection and analysis. Saf. Sci. 119, 240–251.

4) Bickley, S. J., & Torgler, B. (2021). A systematic approach to public health–Novel application of the human factors analysis and classification system to public health and COVID-19. Safety Science, 140, 105312.

5) Bousfot Widad (2023), *Contribution to the investigation of accidents at work in Algerian companies".* PhD thesis, presented at the IHS - University of Batna

6) Cohen, T. N., Francis, S. E., Wiegmann, D. A., Shappell, S. A., & Gewertz, B. L. (2018). Using HFACS-healthcare to identify systemic vulnerabilities during surgery. American Journal of Medical Quality, 33(6), 614-622.

7) Comberti, L., Demichela, M., & Baldissone, G. (2018), "A combined approach for the analysis of large occupational accident databases to support accident-prevention decision making", Safety Science, Vol.106 No.1, pp.191-202.Auteur, Auteur. (année) Titre de l'ouvrage, Editeur.

8) ElBardissi, A. W., Wiegmann, D. A., Dearani, J. A., Daly, R. C., & Sundt III, T. M. (2007). Application of the human factors analysis and classification system methodology to the cardiovascular surgery operating room. The Annals of Thoracic Surgery, 83(4), 1412-1419.

Volume 63 | Issue 07 | July 2024
DOI: 10.5281/zenodo.12798768

9) Ergai, A., Cohen, T., Sharp, J., Wiegmann, D., Gramopadhye, A., & Shappell, S. (2016). Assessment of the Human Factors Analysis and Classification System (HFACS): Intra-rater and inter-rater reliability. Safety science, 82, 393-398.

10) Fu, G., Xie, X., Jia, Q., Li, Z., Chen, P., & Ge, Y. (2020), "The development history of accident causation models in the past 100 years: 24Model, a more modern accident causation model". Process Safety and Environmental Protection, Vol.134 No.1, pp. 47-82.

11) Garrett, J. W., & Teizer, J. (2009). Human factors analysis classification system relating to human error awareness taxonomy in construction safety. Journal of construction engineering and management, 135(8), 754-763.

12) Harris, D., Li, W., 2019. Using Neural Networks to predict HFACS unsafe acts from the pre-conditions of unsafe acts. Ergonomics: Ergonomics and Human Factors. Aviation 62 (2), 181–191.

13) Hulme, A., Stanton, N. A., Walker, G. H., Waterson, P., & Salmon, P. M. (2021). Are accident analysis methods fit for purpose? Testing the criterion-referenced concurrent validity of AcciMap, STAMP-CAST and AcciNet. Safety science, 144, 105454.

14) Jacinto, C., Soares, C. G., Tiago, F., & Silva, S. A. (2011), "The recording, investigation and analysis of accidents at work (RIAAT) process", Policy and practice in health and safety, Vol.9 No.1, pp.57-77.Auteur, Auteur. (année) Titre de l'article. Actes de la Conférence XYZ, pages.

15) Jalali, M., Dehghan, H., Habibi, E., & Khakzad, N. (2023). Application of "Human Factor Analysis and Classification System"(HFACS) Model to the Prevention of Medical Errors and Adverse Events: A Systematic Review. International Journal of Preventive Medicine, 14, 127.

16) Kandemir, C., & Celik, M. (2021). Determining the error producing conditions in marine engineering maintenance and operations through HFACS-MMO. Reliability Engineering & System Safety, 206, 107308.

17) Kwasiborska, A., Kądzioła, K., (2023), "Application of causal analysis of disruptions and the functional resonance analysis method (FRAM) in analyzing the risk of the baggage process." Scientific Journal of Silesian University of Technology. Series Transport. Vol. 119, No.1, pp. 63-81.

18) Li, Y., Cheng, Z., Yip, T. L., Fan, X., & Wu, B. (2022). Use of HFACS and Bayesian network for human and organizational factors analysis of ship collision accidents in the Yangtze River. Maritime Policy & Management, 49(8), 1169-1183.

19) Morrish, C. (2017), "Incident prevention tools–incident investigations and pre-job safety analyses", International Journal of Mining Science and Technology, Vol.27 No.4, pp.635-640.

20) Ma, L., Ma, X., Lan, H., Liu, Y., & Deng, W. (2022). A data-driven method for modeling human factors in maritime accidents by integrating DEMATEL and FCM based on HFACS: A case of ship collisions. Ocean Engineering, 266, 112699.

Volume 63 | Issue 07 | July 2024
DOI: 10.5281/zenodo.12798768

21) Neuhaus, C., Huck, M., Hofmann, G., St. Pierre, M., Weigand, M. A., & Lichtenstern, C. (2018). Applying the human factors analysis and classification system to critical incident reports in anaesthesiology. Acta Anaesthesiologica Scandinavica, 62(10), 1403-1411.

22) Niciejewska, M., Idzikowski, A., & Škurková, K. L. (2021), "Impact of technical, organizational and human factors on accident rate of small-sized enterprises", Management Systems in Production Engineering, Vol.29 No.2, pp.139-144.s

23) Qiao, W., Liu, Y., Ma, X., & Liu, Y. (2020). A methodology to evaluate human factors contributed to maritime accident by mapping fuzzy FT into ANN based on HFACS. Ocean Engineering, 197, 106892.

24) Reason, J., Manstead, A., Stradling, S., Baxter, J., & Campbell, K. (1990). Errors and violations on the roads: a real distinction?. Ergonomics, 33(10-11), 1315-1332.

25) Salmon, P. M., Cornelissen, M., & Trotter, M. J. (2012). Systems-based accident analysis methods: A comparison of Accimap, HFACS, and STAMP. Safety science, 50(4), 1158-1170.

26) Shappell, S., & Wiegmann, D. A. (2004). HFACS analysis of military and civilian aviation accidents: A North American comparison. In Proceedings of the Annual Meeting of the International Society of Air Safety Investigators (pp. 2-8). Australia: Gold Coast.

27) Simon, J. R., & Berbaum, K. (1990). Effect of conflicting cues on information processing: the 'Stroop effect'vs. The 'Simon effect'. Acta psychologica, 73(2), 159-170.

28) Svertoka, E., Saafi, S., Rusu-Casandra, A., Burget, R., Marghescu, I., Hosek, J., & Ometov, A. (2021), "Wearables for industrial work safety: A survey". Sensors, Vol. 21 No; 11, p.3844.

29) Swuste, P., van Gulijk, C., Groeneweg, J., Guldenmund, F., Zwaard, W., & Lemkowitz, S. (2020), "Occupational safety and safety management between 1988 and 2010", Safety Science, Vol.121 No.1, pp.303–318.

30) Theophilus, S. C., Esenowo, V. N., Arewa, A. O., Ifelebuegu, A. O., Nnadi, E. O., & Mbanaso, F. U. (2017). Human factors analysis and classification system for the oil and gas industry (HFACS-OGI). Reliability Engineering & System Safety, 167, 168-176.

31) Wang, L., Cao, Q., & Zhou, L. (2018). Research on the influencing factors in coal mine production safety based on the combination of DEMATEL and ISM. Safety science, 103, 51-61.

32) Wasungu, B. D., & Wognin, S. B. (2018), "Accidents du travail dans une entreprise minière au Togo, de 2013 à 2014", Archives Des Maladies Professionnelles et de l'Environnement, Vol.79 No.2, pp.131–137. Britain". The Oxford Handbook of Disability History, pp.177-93.

33) Wiegmann, D. A., & Shappell, S. A. (2001). A human error analysis of commercial aviation accidents using the human factors analysis and classification system (HFACS).

Volume 63 | Issue 07 | July 2024
DOI: 10.5281/zenodo.12798768

34) Woolley, M. J., Goode, N., Read, G. J., & Salmon, P. M. (2019), “Have we reached the organisational ceiling? A review of applied accident causation models, methods and contributing factors in construction”, Theoretical issues in ergonomics science, Vol.20 No.5, pp.533-555.

35) Wrigley, E. A. (2017), “The supply of raw materials in the industrial revolution”, In The causes of the industrial revolution in England , Routledge, pp. 97-120.

36) Xia, J., Liu, Y., Zhao, D., Tian, Y., Li, J., Zhong, Y., & Roy, N. (2021). Human factors analysis of China's confined space operation accidents from 2008 to 2018. Journal of loss prevention in the process industries, 71, 104480.

37) Xu, M., David, J. M., & Kim, S. H. (2018), “The fourth industrial revolution: Opportunities and challenges”. International journal of financial research, Vol.9 No.2, pp.90-95.

38) Ye, G., Tan, Q., Gong, X., Xiang, Q., Wang, Y., & Liu, Q. (2018). Improved HFACS on human factors of construction accidents: a china perspective. Advances in Civil Engineering, 2018(1), 4398345.

39) Yoon, Y. S., Ham, D. H., & Yoon, W. C. (2017). A new approach to analysing human-related accidents by combined use of HFACS and activity theory-based method. Cognition, Technology & Work, 19, 759-783.

40) Zarei, E., Yazdi, M., Abbassi, R., & Khan, F. (2019). A hybrid model for human factor analysis in process accidents: FBN-HFACS. Journal of loss prevention in the process industries, 57, 142-155.

41) Zhan, Q., Zheng, W., & Zhao, B. (2017). A hybrid human and organizational analysis method for railway accidents based on HFACS-Railway Accidents (HFACS-RAs). Safety science, 91, 232-250.

42) Zheng, R., Guan, X., & Jin, X. A. (2023). Extremal trees and unicyclic graphs with respect to spectral radius of weighted adjacency matrices with property P∗. Journal of Applied Mathematics and Computing, 69(3), 2573-2594.