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A field study on human factor and safety performances in a downstream oil industry

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ABSTRACT

Safety culture and awareness by workers are pivotal tools for the implementation of systematic procedures aiming to risk mitigation in the process industry. The evaluation of human factors on safety performance can reveal unsafe attitudes and failures in training, supervision and management, whose correction greatly contribute to the enhancement of safety program. In this work, the role of human factors in an oil industry was studied by the collection of field data through a structured questionnaire filled by shift, daily and outsourced workers. A deep investigation on the variables involved in the process was carried out, firstly quantifying three conceptual key dimensions (individual, human resource management, equipment and technology) and then analyzing data by means of Response Surface Methodology (RSM), to identify the statistical significant factors and the overall level of safety awareness, behaviour and risk perception of the respondents.

1. Introduction

The role of human factors in accident occurrence is still a burning issue in safety science. Historically, the importance of introducing this topic into the debate has been highlighted by the major accidents of Tenerife (1977) and of Three Miles Island (1979), in which the main cause of the disasters was traced back to human error (Chen et al., 2013), followed in 1984 by the Bhopal gas tragedy, representing a chain of events and human errors which could have been broken at many points, both from an organizational and a technical view point (Palazzi et al., 2015). Whereas at the start of safety history, emphasis was to explain accident phenomena in hindsight and problems to be discussed had a highly technical and chemical-physical content, currently organizational and human factors play an important role and the challenge is to predict in foresight by risk assessment that a planned procedure and route is acceptably safe (Pasman and Fabiano, 2021). As amply reported, two assumptions should be considered in the study of human factors: firstly, humans are erroneous, but in a system perspective the human error arises from a discontinuity between human capabilities and system demands (Bevilacqua and Ciarapica, 2018) and can be also the symptom of technical or organizational issues (Vogt et al., 2010). Secondly, all people respond to safety training courses and try to apply the acquired knowledge to get out of an unsafe situation, albeit with different results. For example, in 2013, the Spain's deadliest train derailment caused the tragic loss of 80 lives. Investigations revealed that the human error was a primary factor as driver powered the train into a left curve at a speed two times higher than the one considered as safe (Shultz et al., 2016). On the other hand, Captain Chesley Sullenberger of U.S. Airways Flight 1549, due to expert crew performance, saved the lives of all the passengers by landing the plane safely in the Hudson River (Eisen and Savel, 2009; Garcia, 2016). Analysis of human factors is very helpful in determining the relationship between human beings and the working environment and its application led to a reduction of errors in several industries (Kohn et al., 1999). In health care systems, human factors knowledge helps in designing new procedures and is critical for improving healthcare quality and patient safety (Carayon et al., 2014). In maritime history, the Human Factors Analysis and Classification System, adapted to the maritime context, showed that most of the collisions are due to decision errors. Thus, it revealed that the role of human factor was crucial in accidents and the detailed analysis proved that the major cause of accidents was dilemma of coordination between vessels or members of the same crew (Chauvin et al., 2013). More recently, three high profile passenger ship accidents revealed wrong risk estimates due to lapses in concentration and technical errors, as well as failure to ensure that safe practices are followed at all times and emergency procedures are promptly activated (Vairo et al., 2017). Similarly,

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Reinach and Viale (2006) reported that accidents caused by human factors accounted for a significant percentage of all train accidents. In both downstream and upstream industries, planning and preparation for facing the worst conditions, are pivotal aspects to ensure the personnel could successfully deal with emergency. It should be noted that human error is not necessarily due to incompetence, lack of motivation, or lack of action, but is determined by multiple occurrences for a particular situation and environment. However, it is generally assumed that operators implement unintentional errors, although they might be well trained and educated, including real errors, violations, deviations, and lapses. Fabiano et al. (2008) reported an exponential decreasing trend in occupational fatalities and injuries in Italy, but redundant avoidable injuries are still happening with human failures classified as lack of training or instruction, lack of motivation, lack of physical or mental ability, slips and lapses of attention. In the industrial sector, it is acknowledged that the investigation about origins and consequences of accidents and near misses over the long period can provide useful tools to enhance risk assessment and management, while advanced accident analysis techniques include the evaluation of the organizational process as a key factor in breaking the accident trajectory. Thus, defences-in-depth, provided by novel approaches involves training, procedures, supervision and leadership, and communication networks (Kontogiannis, 2012). Indeed, it is reported (Mc Lain and Jarrel, 2007) that safety management efforts focusing only on the hazards fail to eliminate many accidents, being the cause connected to many factors including technology, safety climate, social influences, production, and safety demands. Furthermore, the organizational and all aspects of human factors are listed into the prioritized research topics as they play a significant role in major accidents causation, such as shorter time on the job, less dedication, additional complications in case of outsourcing and training deficiencies to name a few (Laurent et al., 2021). Given the importance of injury severity predictions, novel complex approaches are recently explored in the occupational accident domain, such as the machine learning techniques using both reactive and proactive data (Srakar et al., 2020). This requires the investigation of the significance of both types of data in prediction of injury severity. Different strategies have been developed to identify the most significant factors influencing the trend and severity of accidents at work in manufacturing and process industry (Azadeh and Zarrin, 2016, Kontogiannis, 2012). In the recent past, Grote and Kunzler (2000) applied a questionnaire-based approach to elicit aspects of organizational culture and developed a related safety management theory. In the present work, the effect of human factors in a downstream oil industry was investigated by developing *ad-hoc* questionnaires and following statistical evaluation from respondents of two different industrial sites. The main goal of the questionnaire was to highlight the participants' perceptions relating to different aspects of safety in their workplace, considering that the action of the workforce in the given sector may be influenced by a number of things, e.g., the equipment availability, the organization of working environment and the competence and attitude of individuals (Fabiano et al., 2004). As a basic limitation, we quote that some missing information, that could have evidenced the differentiation of the results in relation to the actual activity performed and plant working line, were not analyzed due to a "cautionary interpretation of the privacy law". Additionally, likewise in other questionnaire–based studies, respondents are invited to espouse their cognitions or attitudes at best, that is, the very thing called espoused values by Schein (1992). In this paper, which takes inspiration from a recent work by Fabiano et al. (2019), a thoroughly investigation on the collected data and variables involved in the process was carried out including a RSM based approach to identify the significant factors and the level of risk perception of the respondents from data. RSM is a set of mathematical and statistical techniques widely employed in several branches of the scientific research like analytical chemistry (Bezerra et al., 2008; Peng et al., 2019) and in energy applications (Mäkelä, 2017). Furthermore, Zhang et al. (2018) used RSM as a tool for system sizing of nearly/net zero energy buildings under uncertainty, while Goswami et al. (2016) developed an improved iterative method for the reliability analysis. Although the potential of this technique has emerged in several scientific fields, its application within the topics of safety and risk analysis is largely unexplored. In this regard, few studies are available in the international literature, starting from its first adoption in the safety domain for the statistical analysis and prediction of occupational accidents in industrial contexts (Fabiano et al., 2010; Fabiano et al., 2008). RSM was then utilized as an evaluation tool of the leader-team perceptual distance in relation tosafety leadership and employee safety self-efficacy (Tafvelin et al., 2019), while Van Weyenberge et al. (2017) adopted the technique for quantitative risk analysis addressing life safety in case of building fires.

The remainder of this paper is organized as follows: section 2 illustrates the study methodology including the definition of safety dimensions, questionnaire design and research limitations. Section 3 presents results and relevant descriptive statistics. Section 4 discusses main findings including proper analysis by RSM proposed modeling. Conclusions are drawn in section 5.

2. Methodology

The methodology adopted to find coherencies and discrepancies in the overall safety level and employees' awareness of risk has comprised the construction of two questionnaires for data collection and a subsequent statistical analysis, applying a multilevel model of the information collected.

2.1. Definition of the safety performance indicators

In the industrial context, the introduction of indicators resulted as a useful tool to obtain information about internal results of activities and processes, in such a way that potential risks could be monitored. However, safety management requires a broader vision including also the interactions with all the stakeholders to reach a comprehensive approach to face potential safety problems.

For the purposes of this study, the selected indicators were grouped according to the scheme used for the classification of the topics evaluated during the analysis of questionnaires.

2.1.1. Individual

The first topic is related to the *individual* dimension. Reason (1990) clearly pointed out how individual unsafe behavior represents one of the key factors that directly influence the rate of accidents. For the purposes of safety in the workplace, workers' training plays a pivotal role in providing the ability to identify and manage hazards (Fabiano et al., 2008). Thus, risk evaluation must be carried out by a proper methodology, systematic procedures must be applied and updated, staff roles and responsibilities as well as the provisions and requirements deriving from the legislation and the safety management must be identified. Company internal emergency plan is fundamental to manage the emergency internally with internal resources, identifying possible accident scenarios, the immediate mitigation of emergencies, the system to alert the external resources of emergency and the procedure for reviewing and updating the emergency plan. Four indicators referred to these topics were selected, i.e., Behavior, Attitude towards Safety, Reaction to Near-Miss/Incident, and Communication. The former indicator includes every aspect in relation to task execution, such as the degree of management involvement in activities related to safety and operators' ability to use the safety equipment properly. Attitude toward safety is the indicator involving factors tied to self-safety, awareness and knowledge of the hazard associated to the process, while Reaction to Near-Miss/Incident concerns the appropriate actions to anticipate or eliminate the hazard and prevent unsafe conditions, or damage escalation. Finally, Communication is the indicator that incorporates the formal and informal communication in relation to plant items, operational, safety personnel and process, able to indicate also whether operators consider the management as a source of information on chemical risk and safety.

2.1.2. Human resource management

Competence of personnel is fundamental for safety and the correct management of a company. Adequate information must be provided to workers in relation to their role into the overall organization, about tasks and activities to be carried out. Procedures for personnel recruitment, training and updating, revisions to check operators' satisfaction level and understanding must be defined, applied and shared. To improve safety within the company, it is necessary to monitor the number of accidents attributed to the missing procedures, inadequate procedures, or procedures not followed. We assumed the following items, as indicators of these aspects: Procedures, Education and Training, Accountability, and Motivation. The first indicator includes the level of understanding and application of protocols by the operators, the level of knowledge of practical application of regulations/ safety regulations by operators, managers and other worker categories, the number of accidents due to incomplete procedures, or to visitors as primary or underlying cause, etc. Education and training accounts for all elements inherent in formation and information activities, including the training adequacy and the number of accidents that can be connected as root cause to this item. Accountability is the indicator of the real staff performance in the execution of the emergency plan (in compliance with the coordination of efforts) both in emergency drills and in real situations, aimed to evaluate the degree of accountability and inter-level working group. The last indicator, i.e. Motivation, exhibits the sensitivity and adhesion of the staff to the strategic guidelines laid down by the company, particularly in the safety field.

2.1.3. Equipment and technologies

Working conditions are an important element to be monitored. Application of ergonomics in the workplace can offer positive effects in the reduction of injuries and damages to the environment as well as for the improvements of productivity, job satisfaction, and safety (Azadeh and Zarrin, 2016). Verification of equipment, maintenance and inspections must be adequate and protocols aimed to the evaluation of the workers' exposure to hazardous and toxic substances are fundamental to establish the correct personal protective equipment. For this reason, Working Conditions, Protection and Risk Mitigation, Layout and Maintenance, and Plant Stress were selected as indicators of these aspects. Particularly, Working Conditions dimension refers to conditions of labour objectified by appropriate physical and situational indicators, such as the results of measurements about the exposure in the workplace and the number of complaints by operators related to working conditions. Protection and Risk Mitigation is the indicator referred to the fixed equipment, addressing both risk prevention and protection, as well as personal protective equipment, number of accidents ascribed to unknown risks, percentage of accidents due to an inadequate working environment as primary or underlying cause, etc. Layout and Maintenance involves technical aspects, as well as the preventive and corrective actions in the different plant sections. Instead, the indicator Plant Stress covered the aspects related to the improvements of production and maintenance efficiencies obtained by a safety management system, to the presence of open door policy and a "non-punishment" atmosphere related to communications of safety issues, an, more generally, to autonomy, to the ambiguity of roles and to production pressure.

2.2. Questionnaire structure and sample

Two questionnaires were developed to obtain a careful assessment of the actual situation in terms of safety culture at the level of operational staff and distributed to the workers of two refineries of the same company located in two different sites in Italy. As previously remarked, it should be noted that some of the information deemed essential for the differentiation of results in relation to the actual activity/working area is absent due to constraints in the processing of questionnaires, following a precautionary interpretation of the privacy legislation. The main purpose of the questionnaire is collecting data on a variety of control variables relating to personal characteristics of respondents. The main section of the questionnaire was designed to characterize technical, organizational, and individual factors of suffered injuries, as well as to find out how firms try to reduce the occupational risk to which temporary employees may be exposed. For the purposes of this work, the sample was composed of 683 workers, belonging to the categories reported in Table 1.

The questionnaire aimed also at highlighting the participants' perceptions relating to different aspects of the safety culture in their workplace. It was developed in a semi-structured interview by adopting, where possible, Likert-type scales, even during drawing stage, trying to maximize the number of categories on the basis of the item of interest. In order to maintain the integrity of the results, the impossibility of duplication of the questionnaire by the same worker was accurately verified.

2.3. Limitations of questionnaire data

The questionnaire was distributed to the workers having familiarity with the hazard, personal safety, and processes. However, the answers and the results of the analysis must be primarily interpreted as objective elements, able to reveal specific aspects and perceptions about the working environment and safety culture within the refinery. Being the questionnaire developed as a part of wide research project, further to the items previously outlined, two additional limitations in this study must be considered, namely:

- apparently, there is no such legal reference standard, or external benchmark data;
- there is no actual base line of the Company to be compared with the obtained data.

It should be also noted that the questionnaire section regarding suffered accidents do not distinguish between the nature and severity of injuries. Overcoming these limitations may justify future research developments.

2.4. Ad-hoc evaluation diagrams

The questionnaire has been divided into three dimensions for the evaluation, based on the answers to *key questions*. Table 2 shows the considered dimensions and codifications.

For each explored dimension (Individual, Human Resources Management, and Equipment and Technologies), four items were considered to characterize the workers of the refinery, as briefly reported in the Table 2. The evaluation of the three dimensions is presented using a particular diagram developed *ad hoc* and structured on three semi-quantitative levels (critical, range 0–1; medium, range 1–2; optimal, range 2–3), visually characterized by different colours of immediate visual understanding (Fig. 1).

Globally, the combination of the three categories A, B and C are conceived as illustrating that the overall safety level within the firm results from individual level attitudes (related to safety culture), shared organisational attitudes (related to management system), and specific

Table 1
Classification of workers involved into the study.

Type of workers	Total
Daily workers	97
Shift workers	410
Total internal workers	507
Out-sourced workers	176

Table 2
Categories applied for the evaluation of questionnaire results.

Dimension	Code	Item
	A1	Behaviour
	A2	Attitude Towards Safety
	A3	Reaction to Near-Miss / Incident
	A4	Communication
	B1	Procedure
	B2	Education and Training
	B3	Accountability
	B4	Motivation
	C1	Working Conditions
	C2	Protection and Risk Mitigation
	C3	Layout and Maintenance
	C4	Plant Stress

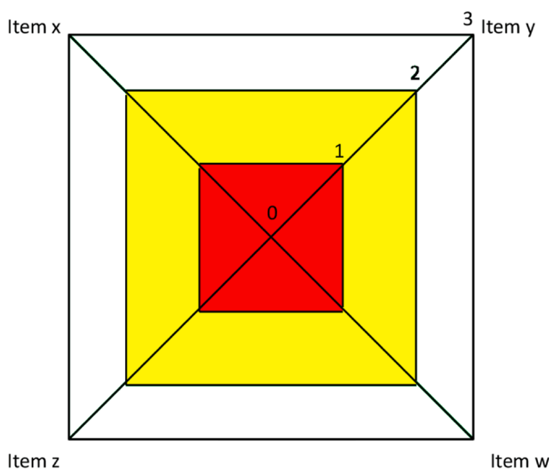

Fig. 1. General three-scale evaluation diagram.

local conditions related to the plants and processes. In this regard, the effectiveness of adequately designed questionnaire to investigate global safety climate at individual and organizational level was clearly discussed by Guldenmund (2007).

As an indication of actual applicability, the most significant results emerged during the first evaluation are systematized according to the following key points:

- *Elements of consistency*: show the main significant results, a positive value, consistent with an optimal policy of the HSE group.
- *Elements of diversion*: highlight the main results in statistically significant value, in the range that goes from minor deficiencies to potential problems with the objective of an effective safety program.
- *Lines of intervention*: early technical/strategic indications integrated as part of the on-going safety.

The obtained results were further processed by techniques of inferential statistics and ANOVA, in order to show significant correlations between accidents and involvement of human factors. The in-depth analysis of the results in the form of statistically significant variables is provided through RSM technique, with the aim of highlighting the significant variables for the purposes of safety in the refinery and the level of risk perception of respondents. It also will attempt to ascertain, by means of answers analysis, if there were errors attributable to behavioural violations of rules.

2.5. Response surface methodology

Response surface plots were used to visualize potential dependences of the response variables (behaviour, safety attitude, communication, plant stress, and training) on the input variables experience and age of workers. The latter was grouped into categories from A to E corresponding to the meanings reported in the second column of Table 3 (category S indicates non-responses), while values of the input variable Experience of workers were summarized in the third column of the same table.

Response variables are plotted according to the mean values obtained by questionnaire results, ranging from 0 to 3. Lower values had negative meaning and are depicted by red color into the surface plot, while higher values are reported in green and have positive valence. Three-dimensional plots were built for all the categories of workers involved into the questionnaire, i.e., daily, shift and out-sourced workers.

The software Statistica (Statsoft version 10.0) was used for data elaboration. Indeed, results were statistically evaluated to assess the significance of correlations between the input and output variables.

Under the following hypotheses:

a) independent cases;
b) normal distribution of variables;
c) each variable was measured inside a scale range or fraction,

Pearson coefficient r, ranging from −1 (inverse correlation) to 1 (linear correlation), allowed comparing two variable groups at time, on the basis of Eq. (1):

$$r = \frac{\sum xy - \frac{(\sum x)(\sum y)}{n}}{\sqrt{\left[\sum x^2 - \frac{(\sum x)^2}{n}\right]\left[\sum y^2 - \frac{(\sum y)^2}{n}\right]}} \tag{1}$$

Where x refers to values of input variables, y refers to the values of the response variables, n is the sample size.

Moreover, *t-test* was performed to check the significance of the calculated correlation coefficient, according to Eq. (2), using:

- null hypothesis: $r = 0$;
- alternative hypothesis: $r \neq 0$.

$$t = \frac{r\sqrt{(n-2)}}{\sqrt{(1-r^2)}} \tag{2}$$

In order to use the table of t-value for the comparison, the degree of freedom (df) was calculated according to Eq. (3):

$$df = n - 2 \tag{3}$$

3. Results

3.1. Descriptive statistical evaluation

Questionnaire addressed to internal workers included 15 closed-ended questions and 1 open-ended question. Six questions were referred to workers experiencing occupational injuries. Instead, for outsourced workers, questionnaire was composed of 19 closed-ended questions and 1 open-ended question. Table 4 shows the descriptive statistics of questionnaires for internal and outsourced workers. From

Table 3
Actual values of the two input variables into the design space, both grouped from A to E.

Letter	Meaning for the input variable AGE	Meaning for the input variable EXPERIENCE
A	workers under 25 years old	less than 1 year of experience
B	workers age 25–35	1 – 2 years of experience
C	workers age 35 – 45	2 – 5 years of experience
D	workers age 45 – 55	5 – 10 years of experience
E	workers age over 55	more than 10 years of experience

Table 4
Descriptive statistics on the results of questionnaires.

		Workers	Workers experiencing occupational injury	Shift workers	Daily workers
Internal workers	Number of questions	69	80	69	69
	Total number of questionnaires	507	71	410	97
	Average number of non-responses	28.19 ± 29	4.1 ± 3.1	21.8 ± 24.58	3.2 ± 4.8
	Non-responses [%]	5.56	5.87	5.32	3.30
Outsourced workers	Number of questions	55	89		
	Total number of questionnaires	186	13		
	Average number of non-responses	8.87 ± 5.18	0.73 ± 0.92		
	Non-responses [%]	4.77	5.62		

data, high standard deviations resulted for the non-responses of internal workers, mainly concerning questions related to age, experience and trainings. In addition, the high percentage of non-responses observed can be at least partially attributable to potential identification concerns. The percentage of non-responses of outsourced workers was lower than that of internal workers.

Figs. 2 and 3 summarize the personal characteristics of respondents respectively in terms of age and work experience. As can be observed in Fig. 2, a percentage of 40.9 % of outsourced workers are in the range from 35 to 45 years old and only the 6.5 % are older than 55 years old. In addition, this category presents the highest percentage of under 25 (4.8 %), while only the 2 % of internal workers are in the same range of age (2.8 % of shift workers and 0 % of daily workers). Most of internal workers was aged 25–35 (22.1 %), but it should be noted the high level (30.6 %) of non-responses related to this aspect, probably due to confidentiality issues.

As reported in Fig. 3, non-responses percentage concerning the experience of respondents was very low for outsourced workers and is about 24.5 % for internals (25.4 % of shift workers and 20.6 % of daily workers). Anyway, 41.9 % of outsourced and 44.8 % of internal workers declared to have more than 10 years of experience in the company.

Data collected about workers experiencing occupational injuries revealed that 9.1 % of internal workers had an experience in the company lower than 6 months, 3.0 % from 6 to 12 months, 16.7 % from 1 to 2 years, while 71.2 % declared that they had more than 2 years of experience at the time of the injury. The 4.7 % of the reported injuries occurred after 0–2 h of work, 45.3 % after 2–6 h, 28.1 % after 6–8 h and 21.9 % after more than 8 h of work. Furthermore, the 22.4% of internal respondents experiencing injuries stated that the injury prognosis was from 0 to 3 days, 25.4 % up to a week, 28.4 % up to a month, 10.4 % up to 3 months, and 13.4 % more than 3 months. The operations carried out by internal respondents at the time of the injury were related to normal operations (66.7%), to transport (7.6%), maintenance (12.1%) and emergency situations (13.6%), and concerned accident in vehicles (2.5%), contact with fire (1.3%), contact with toxic / corrosive substances (16.3%), inhalation of toxic / irritating substances (8.8%), falls from high plant areas (3.8%), falling from platforms and / or scaffolding, falling on the floor by stumbling or sliding (30.0%), impact against thrown or falling objects (8.8%), impact with parts of machinery or moving objects (5.0%), crushing by objects (8.8%), lifting or moving objects (6.3%), explosion (3.8%), electric discharges (1.3%), accident caused by motor vehicles, excavator forklifts, etc. (2.5%). The perceived causes of the accident involved natural external events for 13.5% of the respondents, events caused by other workers for 7.9%, inadequacy of personal protective equipment for 10.1%, low level of safety of the equipment for 9.0%, lack of specific training for 2.2%, haste (24.7%), difficulty in carrying out operations for 12.4%, while 20.2% of respondents believed that the cause lies elsewhere.

The analysis of data collected regarding outsourced workers, showed that the 84.6 % of respondents declared to have an experience of more than 2 years at the moment of the injury, 7.7 % from 6 to 12 months and 7.7 % of less than 6 months. Most of the accidents occurred after 2–6 h of works (50 %), while 25 % after 6–8 h and 25 % after 0–2 h, leading to prognosis from 0 to 3 days (15.4 %), up to a week (38.5 %), up to a month (23.1 %), and up to 3 months (23.1 %). Moreover, respondents revealed that at the moment of the accident they were carrying out operations related to normal activity (61.5 %), maintenance (30.8 %), and emergency (7.7 %). The accidents regarded falling on the floor by stumbling or sliding (30.8%), impact against thrown or falling objects (23.1%), impact with parts of machinery or moving objects (15.4%), crushing by objects (7.7%), lifting or moving objects (15.4 %), and electric discharges (7.7%). According to the outsourced workers experiencing injuries, the main causes can be ascribed to troubles during the operation (21.4 %), external natural events (14.3 %), other operators

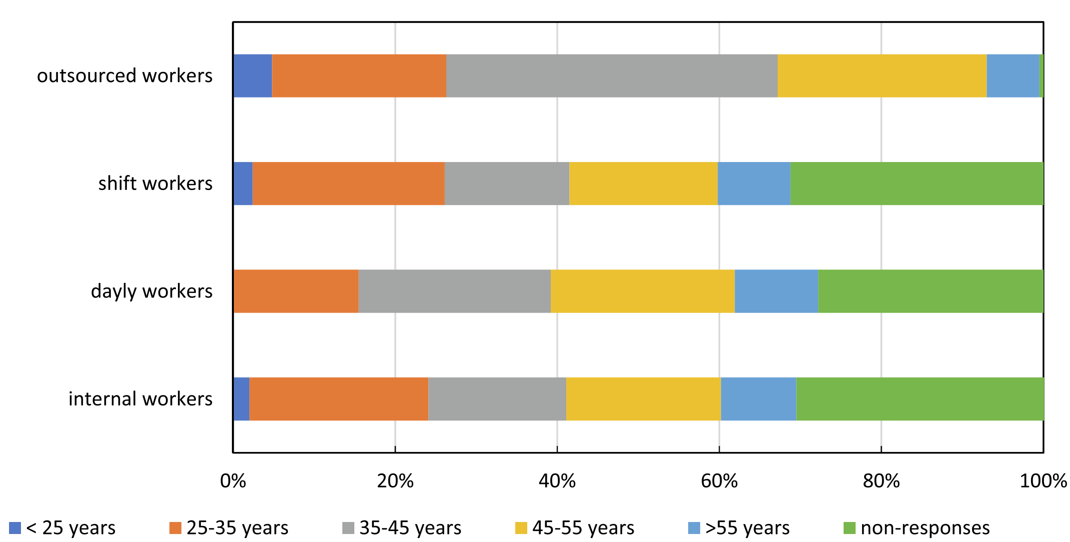

Fig. 2. Results of the questionnaire concerning the range of respondents age.

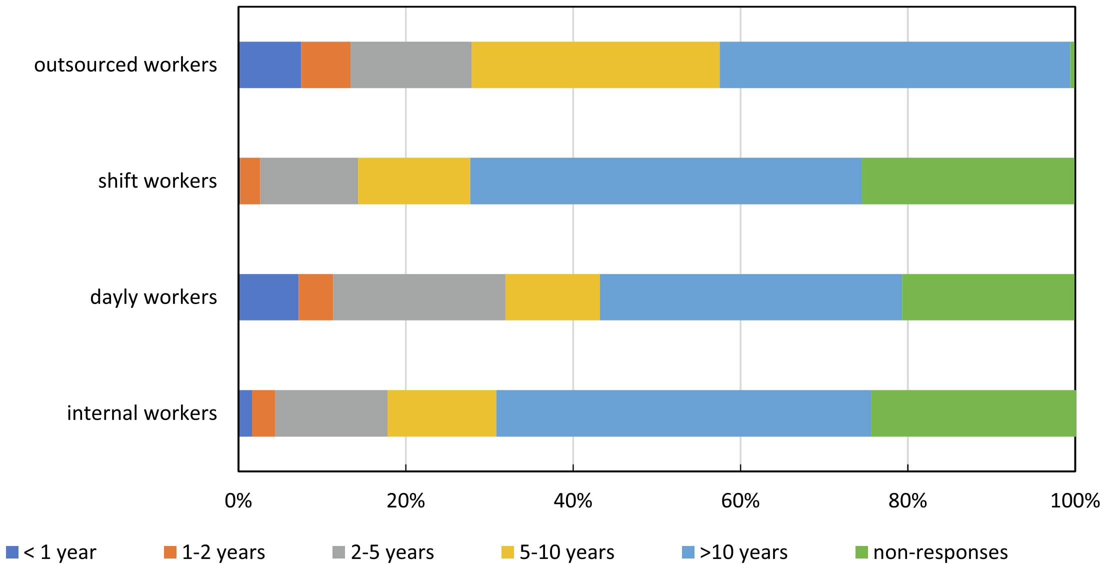

Fig. 3. Results of the questionnaire concerning the range of respondents experience.

(21.4 %), with other causes collecting 28.6 %.

4. Discussion

Results from questionnaire elaboration are discussed in the following, by considering the three dimensions previously introduced, namely: individual, human resources management, equipment and technologies.

4.1. Individual

Individual behaviour of the workers is determined by considering four relevant categories: behaviour, attitude towards safety, reaction near-miss / incident, communication, as shown in Fig. 4.

Formally, a clear behavioural attitude of respect towards the operating procedures and attention for hazards relating to specific activities, together with a proactive operational approach emerged from collected data. Similar attitude was reported by the outsourced workers' questionnaires. As elements of deviation, it should be noted that 45.3% of answers indicated that occasionally violations took place, related to those risks which are considered less serious, or less likely (e.g., failure to use personal protection equipment (53.6%), failure to observe regulations on vehicular traffic (60.1 %)). The high number of non-responses related to particular questions could indicate that workers were aware about the danger of certain actions and the tendency to maintain these behaviours. Particularly, daily workers showed less attention related to the use of personal protection equipment (68.1 %) compared to shift workers (40.9 %). Recommendations: a) targeted training on specific risks and behavioural role; b) random field supervision and Inspection by the management; c) speed control systems of vehicles in transit and traffic offences, combined with proper economic fines in case of rule violations.

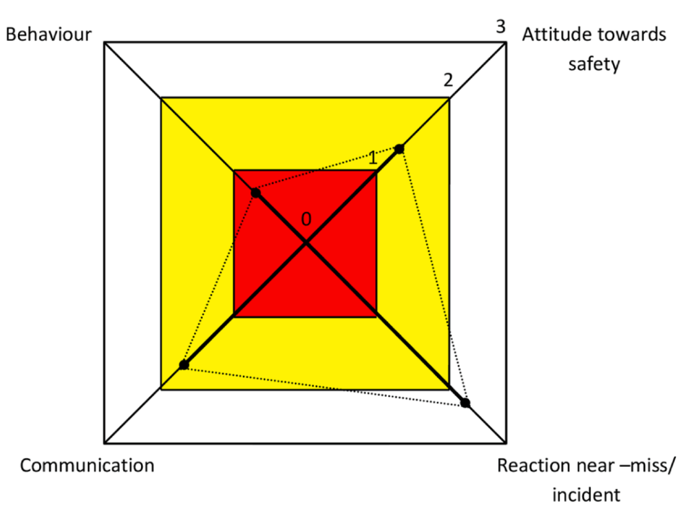

Fig. 4. Evaluation diagram of the Individual dimension.

Attitude of workers towards safety reflects a good knowledge of emergency procedures. 74.7% of internal workers reported the efficacy of training. It was also observed that 70.2% of the responses were obtained from the people working in dangerous conditions, denoting consciousness to operate under hazardous conditions. 85.7% of outsourced workers express the awareness of being in potentially dangerous situations. Training to face emergency situations is pivotal, so it should be improved. 74.9% of internal workers expressed a discrepancy between the required operations and the actual time needed to carry out the operations. Indeed, 25.9% of workers agree with literature, reporting that the main cause of injury is production pressure. 66.3% of respondents express a tendency to by-pass procedures recognized as too slow or complex and it can be observed a statistically significant figure (48.7%) perceiving that routine operations are not completely safe. This percentage is even higher in shift workers (77.0%) due to increased exposure time to the hazard-specific job. For outsourced workers, safety procedures were also not fully well-known and applied by a statistically significant percentage of respondents (39.5%). This item is amply explored in the literature and empirical evidence suggests that procedures in complex environments, such as a refinery or a process plant, are sometimes misunderstood, outdated, or simply not used (Bullemer et al., 2004). Results highlighted a tendency of bypassing the procedures (56.0%). The 61.3% of the workers indicated the non-application of safety standards and procedures in relation to IPRs. A percentage of 66.8% of respondents reported a feeling of being in an unsafe condition, at least partially in connection with lack of enforcement of rules and procedures. This item would need further investigation as employee's perception about risks at job is one of the safety climate dimensions to predict accidents/injuries as explained in the review by Flin et al. (2000), commenting a positive correlation between safety climate and safety performance, i.e., the better the safety climate, the fewer the accidents. In this regard, the effect of work experience on risk perception is reported to be small in hazardous settings such as offshore ones

(Rundmo, 1996). Recommendations: a) control over application procedures; b) training / coaching on knowledge of the process and the need to complete the procedures in detail; c) training targeted to specific topics, with an ex-post verification performed by an independent person.

Concerning the reaction to Near Miss, 71.3% of internal workers exhibited awareness of potential accidents, their implications and consequences. Although safety procedures were adequately known and a satisfaction level of 75.1% was reported in the sample, the knowledge about the occurrence of accidents was limited to the immediate causes and it did not extend to the root causes. The result is consistent with the observation that in organisations where there is an absence of good safety culture, the staff at the sharp end will be tempted not to report near misses, either for under evaluation or for management reprisals fear and consequently the organisation as a whole will fail to learn (Allford et al., 2016). Recommendations include deepening the culture of reporting and discussion of accidents and near-misses, to be extended at the level of front-end operators, so to improve the feeling that a reporting culture is a just culture, stimulating as well employees to act in a safety-compliant way.

83.4% of the responses belonging to internal workers showed good mutual communication and understanding between the people who make up their own operational staff, as well as good communication at the time of shift change. Additionally, 77.3% of outsourced workers showed good communication both with internal staff and the company and highlighted the high level of mutual understanding in performing different tasks (87.0%). Nevertheless, 53.3% of the responses of internal workers showed that there were obvious problems of communication between operational staff and maintenance personnel. This problem was more evidenced by shift workers (59.0%). Recommendations: a large organization, such as the given oil refinery, has several interfaces that require clear accountability and good communication, both horizontally and vertically. The results show lack of communication and roles / responsibilities partially unclear. These aspects may cause some confusion in the interface in different situations and therefore would require an intervention.

4.2. Human resource management (HRM)

The aspect related to HRM in the questionnaire was explained under four categories: procedure, education and training, accountability, motivation, as shown in Fig. 5.

Concerning the dimension Procedure, 72% of the workers showed positive intent by following procedures related to safety. However, an issue connected to procedure updating emerged from responses. 87.4% of the validated responses showed a formal adherence to procedures when operations are carried out by outsourced workers. It is worth noting that according to a cross analysis between the results of the questionnaire and adverse events or accidents, 73.9% of the responses revealed the presence of a number of procedures, which were not followed fully, or were mainly disregarded. As explained by further analysis, it appears that the worker adhesion to procedures is determined by the experience level of the worker rather than by the complexity of the specific task. The reason seemed to be traced back to the lack of definition of responsibilities in the procedures and the limited clarity of the protocols. Especially daily workers were involved in this failure. 63.2% of the responses indicated the impossibility of finding an interlocutor for solving problems that arise, while 73.0% claimed explicit difficulties in applying certain procedures. For outsourced workers, the procedures relating to occupational safety were disregarded to a higher degree, indicating a moderate control issue. Recommendations: in order to reduce hazards, procedure verification is recommended, as well as simplification to the greater extent possible.

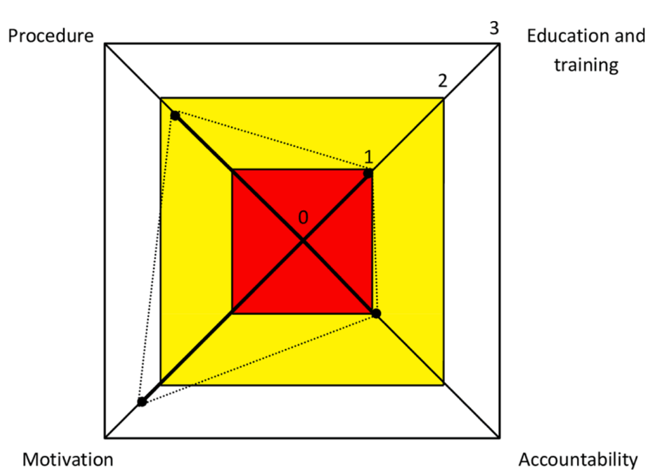

Fig. 5. Evaluation diagram of the Human Resources Management dimension.

Fig. 5 indicates that "Education and training" is the most critical factor in the Human Resources management dimension of HSE. Workers generally consider education and training as important and safety relevant elements. Indeed, only a small percentage (8.9%) of the responses of internal workers showed less sensitivity/ interest in training. This result was fully statistically consistent with the sensitivity to safety issues mentioned in other dimensions. 96.8% of outsourced operators followed a course of training in the last 2 years and for the 78.8 % of respondents the received formation was recognised as satisfactory. The most striking statistical figure is the number of non-responses (36.9%) and staff who do not remember (7.7%) for a total of validated responses to negative value equal to 44.6%. These results also showed that for internal workers the investment and commitment to the training was satisfactory but perception and effectiveness of the training program was not adequate. Operators indicated an extremely variable number of hours of training attended in the last two years ranging from 1 to over 100. For outsourced workers, results revealed that the training received in relation to emergencies was completely satisfactory only in 66.9% of the responses. Globally, the results should be correlated to the effectiveness of OHS risk management within the industrial setting, which relies on the ability of decision-makers to recognize hazards, assess the implication of these hazards, and determine appropriate interventions, as commented by Aires et al. (2010).

Recommendations: the methodology for conducting the training can be implemented with the adoption of subsequent verification tools for learning to assess the effective participation and assimilation of the contents. Additionally, the training of plant operators with experts is considered crucial, in connection with possible interventions downsizing of the workforce and reducing or merging of functions between the two original refineries. This training is of particular importance to internal personnel in relation to the specific knowledge and process plant and its execution therefore should be entrusted with past experience in the same field. Analogously with the related field of security awareness, the organisation of more interactive training sessions where people gain experience with the safety topic by direct experience, or simulation and interactive demos may increase the relationship between their attitudes and behaviour (Sas et al., 2021). Training related to emergencies requires the most effective tools (e.g. interactive simulations and adoption of virtual augmented reality tools). The on-going trend towards Safety 4.0 (Pasman et al., 2021), represents a challenge and a must, including augmented reality use for safety training of operators, implementation of digitalization in all safety management activities such as pre start-up safety review, work permits, standards, safety tours emergency simulations, etc. In this regard, novel tools relying on additive technology, collaborative robotics, virtual or augmented reality are under testing in teaching (Laciok et al., 2020) and dynamic procedures for hazardous process simulation and heuristic evaluations of deviation are applied to offshore oil production processes (Raoni et al., 2018).

Regarding the dimension Accountability, the recorded events of operations carried out without authorization were limited (14.1%).

Accountability is closely second to Education and training in terms of importance in assessing the impact to the Human Resources management dimension. Collected information evidenced that the undesired events are mainly due to the staff of external companies who tend to disregard operational procedures. The information flow related to safety deficiencies from operational core to strategic top management is not appreciable. For outsourced workers, the safety related procedures were particularly disregarded, thus evidencing a critical issue relating actual enforcement control. Recommendations: the rather frequent and obvious infringements of the procedures suggest the need for a more thorough control action as well as a strict enforcement and accountability control of safety rules in permit-to-work procedures.

Results related to Motivation showed significant results for internal workers. The level of involvement in issues related to safety proved to be satisfactory overall. This sensitivity is clearly attributable to the positive adoption of a safety incentive policy, which has been selected as part of the sample under study. In this regard, it is reported that when the management is committed to safety goals (over production goals), safety incentives become more effective (Choudhry, 2014). For outsourced workers, similar considerations can be developed with respect to outsourced companies, although the value, in this case, is to be considered limited to the particular type of sample. For internal operators, responses seemed to indicate that safety at the operational level is interpreted in some instances as compliance with legal requirements. This aspect may be connected with the need of organisational alignment, with leaders providing task-oriented guidance and demonstrating interpersonal (social) support and congruent behaviour, also at the upper management level (Blockland and Renoers, 2021).

Recommendations: a) targets set down by the HSE policy and consistently oriented following a "zero accident" approach should be integrated and benchmarked according to an objective indicator of yearly performance improvement; b) the performance indicator should be developed on the basis of a trend line drawn in the short to medium term (e.g., 5 years) and may represent yearly targets of immediate perception and therefore suitable to increase staff motivation; c) all outsourced companies should be actively involved into the safety performance reward approach.

4.3. Equipment and technologies

Equipment and Technologies in this questionnaire was explained under four categories: working conditions, protection and risk mitigation, layout and maintenance, and plant stress, as shown in Fig. 6.

For what concerns Working conditions, the 90.7 % of internal operators claimed that they cannot be considered as optimal. There were also some physiological and pathological aspects that can be attributed, at least in parts, to deviations from the optimal conduction with

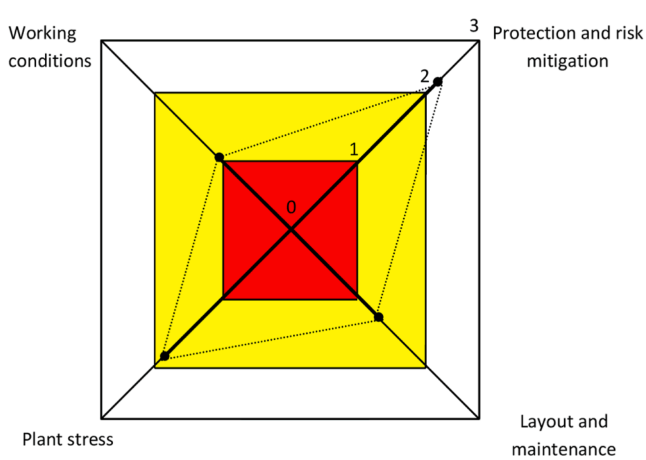

Fig. 6. Evaluation diagram of the Equipment and Technologies dimension.

potential negative consequences for humans and the environment, among which: possible stumble/fall (96.2%), lack of adequate lighting (91.3%), not removed constructions at the end of the work (93.9%). Shift workers tend to emphasize the high frequency of unwanted events. For outsourced workers, 92.3% of the responses showed the occasional presence of non-optimal working conditions. Recommendations: intensify visits to plant even at the managerial level for the implementation of specific corrective actions to value a priority for safety, ergonomics and hygiene in the workplace. Speed-up the checks at the end of temporary activities/maintenance programs.

Protection and mitigation: for internal workers, Personal Protection Equipment (PPE) were available (91.2%) and easy to use. Safety signs were present and understandable (74.8%), in full compliance with current regulations in terms of general guidance and safety program. For outsourced workers, PPE were available (90.6%) and ease of use, safety signs were present and understandable. For construction sites, 81.3% of the structures do not have adequate protection as pointed out above by shift workers. Occasionally (33.3%), safety equipment was in poor condition, as pointed out by some adverse events recorded. Similarly, the necessary equipment was not available or was not perfectly consistent with the procedures (51.7%). In the same way, 66.7% of the structures did not have adequate protection and safety equipment was in poor condition (56.7%) and the necessary equipment was not always available or was not perfectly consistent with the procedures (42.8%). Recommendations: intensify visits to different plant lines in the form of "safety walks", considering even the involvement at a managerial level, for the implementation of specific corrective actions, to actually setting up priorities for safety, ergonomics and hygiene in the different workplaces. Benefits from operational experience can be enhanced promoting an open communication between operators, which should not be feel blamed for the event reports, and the management that should be aware of the importance of events identification and related hazards (Markowski et al., 2021).

Results obtained from the plant layout and maintenance section revealed that there were obvious gaps in the application of procedures for the inspection and control. They highlighted some cases of severe corrosion and minor leaks from pipelines and piping, especially as it emerged from the analysis of adverse events and confirmed by the findings of the questionnaire (respectively 55.2 % and 76.8%). The presence of safety signs was optimal and fully complying with safety regulations. However, there was a need for more immediate and understandable indications of hazard in certain areas of the plant or process steps, as reported by a percentage of 58% of internal line workforce. Outsourced workers also reported corrosion (52.8%) and losses from pipeline (51.1%) and pipes (93.9%). Recommendations: develop a procedural system for the prevention and prediction of maintenance, especially on the piping system. Conduct timely inspections to capture on-site evidences of the actual situation.

4.4. RSM evaluation

Analysis by Response surface modelling was performed on the results of questionnaire in order to observe any presence of correlation between the input variables, i.e., age and experience, and the indicators. Fig. 7 depicts the three-dimensional surface plots related to the statistical significant correlations obtained by results of shift workers.

The response communication (Fig. 7a) presented a significant correlation with both the age of shift workers and their experience. It should be evidenced that the effect of work experience is one of the most studied in the safety domain in different industrial settings, also considering that the perception of risk is modified by experience and does not remain unchanged over time (Tierney, 1999; Starren et al., 2013). In this context, a recent paper reported that in the construction sector the effect of the personnel years of experience on their hazard perception reveals a significant difference, due to a lack of adequate and continuous safety training (Abbas et al., 2018).

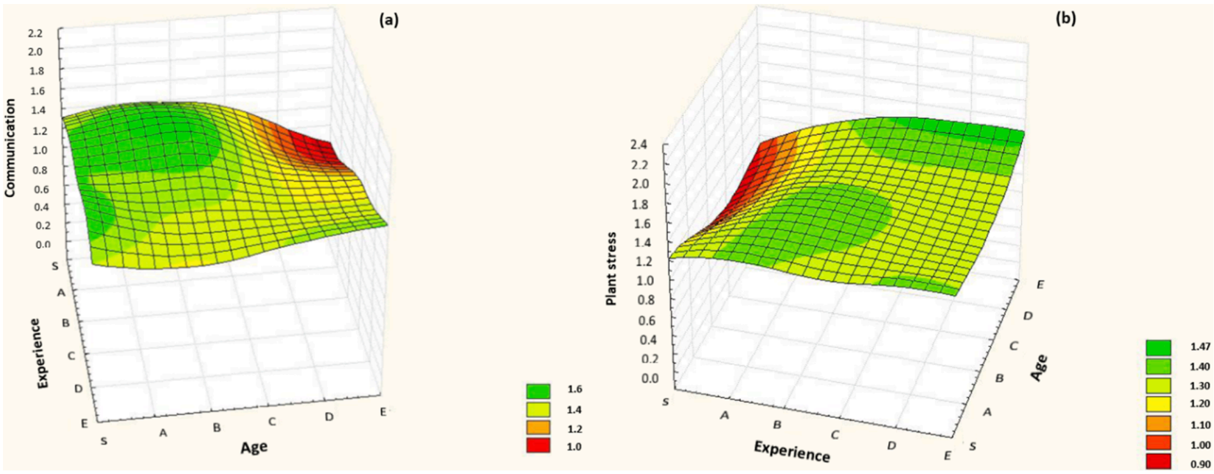

Fig. 7. Three dimension surface plots of response variables a) Communication and b) Plant stress, as functions of the input variables experience and age for shift workers.

As reported in Table 5, statistical evaluation showed a significant correlation between age and communication (r = 0.0959; t value = 1.9459) and between Experience and Communication (r = 0.0841; t value = 1.7057). In addition, a significant correlation between Plant Stress and Age resulted from the data of shift workers' questionnaires (r = 0.1034, t = 2.0992). The observed values of Pearson coefficients showed that the positivity of responses increases as the age of respondents increases both for Communication and Plant Stress, while a higher experience influenced only the positivity of responses related to Communication. As it can be also visualized by the surface shape, such correlation is non-linear.

Responses of daily workers showed a significant and inverse correlation (Fig. 8 and Table 6) between Behaviour and Experience, a positive correlation between Education and Training and Experience, and between Education and Training and Age (Fig. 8b).

Globally, as reported in different studies, it is confirmed that training exerts a significant influence on overall safety behaviours of workers, by improving their technical skills and competence.

For outsourced workers, the response variables showing significant correlations with input variables are visually reported in Fig. 9. Results of statistical analysis are shown in Table 7. It should be remarked that age of respondents, affected at a statistically significant level the results of the dimensions Behaviour (r = 0.1634, t = 2.2464), Attitude toward safety (r = 0.1388, t = 1.9012), and Communication (r = -0.1402, t = -1.921) at a statistically significant level. Additionally, it should be noted that the evaluation of Communication as a function of Age is discordant between shift and outsourced workers. Even if there are studies where the authors did not identify significant differences in perceived risk according to experience (Basha and Maiti, 2013), these findings seem in line with the observation by Mohamed et al. (2009) showing that as experience increases, the risk of the activities is overestimated, viewing a large number of work situations as hazardous, formulating unrealistic situations and altering the normal development of the processes. Following the reasoning of Sas et al. (2021), it must be however stressed that also in the peculiar safety domain, although individual knowledge, safety attitude and behaviour are surely interrelated, they are not necessarily linear or dependent on each other.

Table 5
Correlations between response and input variables from results of shift workers.

Correlations from results of shift workers	Pearson coefficient	t-value	t reference value (α = 0.05; df = 408)
Age - Behavior	0.0066	0.1332	1.6449
Age - Attitude toward safety	−0.0044	0.0896	1.6449
Age - Communication	0.0959	1.9459	1.6449
Age - Plant stress	0.1034	2.0992	1.6449
Age - Education and training	−0.0738	1.4953	1.6449
Experience - Behavior	−0.0055	0.111	1.6449
Experience- Attitude toward safety	−0.0362	0.7307	1.6449
Experience - Communication	0.0841	1.7057	1.6449
Experience - Plant stress	0.0732	1.4829	1.6449
Experience – Education and training	0.0013	0.026	1.6449

5. Conclusions

This paper has presented an experimental study focused on the perceptions of workers of a downstream oil industry relating to different aspects of the safety culture and management in their workplace, including use of procedures and perceived occupational accident causes. A large-scale study involving 507 workers of two process plants and 176 external workers was conducted to investigate relevant safety issues. Despite some limitations, the study provides comprehensive information regarding human factor influence in actual and potential accidents, possibly addressing improvement in the firm safety policy, as well as program development for promoting safety culture. The evaluation approach, even if currently developed at a prototype level, allows the enforcement of a number of practical intervention lines based on questionnaire results. Based on this study, a number of recommendations are made for safety improvement in the plant studied. Indeed, through the recognition of the most influencing factors, improvement items in the HSE management system can be identified and the most effective layers of protection, both mitigating and preventing the risk can be implemented. In view of future investigation, the evolution over time of worker safety behaviour, attitude and awareness, as well as the efficiency of training programmes can be quantitatively assessed by the presented framework, adopting presented empirical results as an internal benchmark of reference.

CRediT authorship contribution statement

Bruno Fabiano: Conceptualization, Supervision, Methodology. **Margherita Pettinato:** Writing – original draft, Visualization. **Fabio Currò:** Formal analysis, Resources, Investigation. **Andrea P. Reverberi:** Validation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial

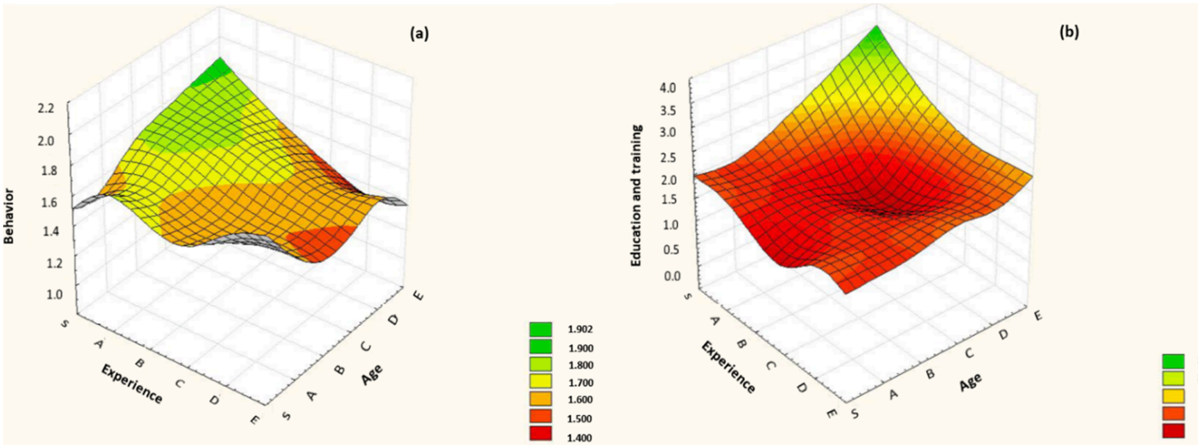

Fig. 8. Three dimension surface plots of response variables: a) Behavior and e) Education and Training, as functions of the input variables experience and age for daily workers.

Table 6
Correlations between response and input variables from results of daily workers.

Correlations from results of daily workers	Pearson coefficient	t-value	t reference value (α = 0.05; df = 95)
Age - Behavior	−0.1305	1.2828	1.66
Age - Attitude toward safety	−0.1521	1.4995	1.66
Age - Communication	0.0745	0.7278	1.66
Age - Plant stress	0.0068	0.0659	1.66
Age - Education and training	0.1691	1.6724	1.66
Experience - Behavior	−0.2679	2.7099	1.66
Experience - Attitude toward safety	−0.1143	1.1217	1.66
Experience - Communication	0.0285	0.2779	1.66
Experience - Plant stress	0.1304	1.282	1.66
Experience – Education and training	0.1975	1.9635	1.66

Table 7
Correlations between response and input variables from results of outsourced workers.

Correlations from results of outsourced workers	Pearson coefficient	t-value	t reference value (α=0.05; df = 184)
Age - Behavior	0.1634	2.2464	1.6449
Age - Attitude toward safety	0.1388	1.9012	1.6449
Age - Communication	−0.1402	−1.921	1.6449
Age - Plant stress	−0.066	−0.897	1.6449
Experience - Behavior	0.1014	1.3824	1.6449
Experience - Attitude toward safety	0.0535	0.7264	1.6449
Experience - Communication	−0.0249	−0.3376	1.6449
Experience - Plant stress	0.0089	0.1203	1.6449

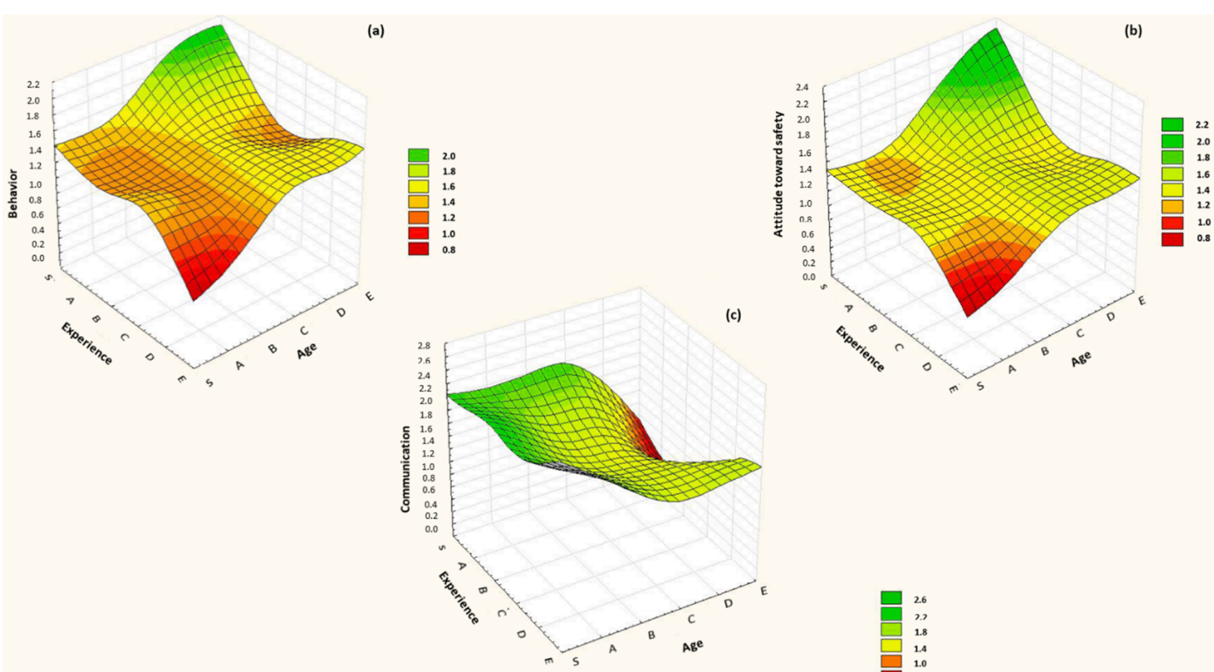

Fig. 9. Three dimension surface plots of response variables: a) Behavior, b) Attitude toward safety, c) Communication, as functions of the input variables experience and age for outsourced workers.

interests or personal relationships that could have appeared to influence the work reported in this paper.

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