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Human Factors and Safety Management: a Field Study on Safety Performance in the Process Industry

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As widely reported in the scientific literature, audits, benchmarking, safety performance indicators and accident data help the management to understand the current safety performance status and to individuate strong and weak areas of the safety management system. Additionally, being process safety incidents relatively rare, as evidenced in the Baker report on BP Texas City accident, safety performance cannot be measured effectively alone on the basis of such high profile incidents. In the first phase of the research program, process and occupational injuries were studied, collecting field data in a large process industry, over five-year observation. Technical and management improvements seem no longer sufficient to promote safety as at-risk behaviour and unsafe attitudes are still present in spite of all training, supervision and guidance. A thorough analysis on underlying causes connected with human failure was subsequently performed by designing a structured questionnaire, for both in-house and outsourced frontline workers. Data statistical analysis allowed quantifying four conceptual key dimensions within the firm, namely: individual behaviour, organizational climate, human resource management and plants/technology. Significant results were utilized to evidence individual and corporate elements affecting accident frequency for the two workforce types. Conclusions were focused on identifying technical and managerial options to reduce the likelihood of errors and increase risk resilience.

1. Introduction

Human factors always play a vital role in occurrence of accidents at the work place. Learning from previous failures is one of the pillars of modern approach to risk management: the ultimate goal of the industrial accident analysis is the generation of lessons learned in order to avoid accident recurrence (Sikorova et al., 2017). Human factor can be defined as the study of all the elements that make easier to do the work in the right way, depending upon the relationship between humans, the tools and equipment used in the workplace and the work environment. Historically, the debate about the involvement of human factor in accident occurrence did not gain immense priority in the psychological domain, until the happening of some major industrial tragedies due to human blunder: collision of two jumbo jets at runway in Tenerife (1977), Three Miles Island incident in 1979 (Chen et al. 2013), and Seveso accident (Fabiano et al., 2017). Additionally, investigations in the maritime history, dealing with collision of two vessels, revealed that the role of human factor was pivotal for the coordination dilemma between vessels or members of same crew (Chauvin et al. 2013) or for erroneous decisions made during emergency, causing accident escalation (Vairo et al., 2017).
In the last few years, new pressures and related safety threats have been developing rapidly, e.g., cost cutting and downsizing, plant complexity and ageing, early retirement, outsourcing, job-hopping, and complacency; high profile process accidents still happen and emphasize the importance of process safety performance metrics to enable and maintain good safety management (De Rademaeker et al., 2014). It should be noted that human error is not necessarily due to incompetence, lack of motivation or lack of attention, but is determined by multiple occurrences for a particular situation and environment. It is however generally assumed that operators implement unintentional errors, although they might be well trained and safety-educated, including real errors, violations, deviations and lapses. In Italy, a clear decreasing trend in occupational fatalities and injuries was observed in last three decades, but still there are redundant avoidable

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injuries happening due to involvement of human factors. Typical reasons for this human failure can be classified as: lack of training or instruction; lack of motivation; lack of physical or mental ability; slips and lapses of attention (Fabiano et al. 2008). In this field, an ongoing effort is dedicated to shed more light on understanding the underlying cultural causes of safe environments (Reniers and Gidron, 2013). Different approaches were developed to identify the most significant factors that influence the trend and severity of accidents at work in manufacturing and process industry, while the scientific community is facing emerging hazards connected to novel materials by developing novel tools suitable to identify preventive and protective measures under the so-called precautionary principle (Fabiano et al., 2019). The development of several accident analyses, which include 'defenses in- depth' such as, training, procedures, supervision and leadership, and communication networks techniques, tried to break accident trajectory in the process industries (Kontogiannis 2012). Reviewing and evaluating the source and residuum of accidents industrial setting, with the help of proper statistical analysis for a longer time span can provide solutions to enhance risk assessment and management (Fabiano and Currò, 2012). In this work, the actual role of human factor in a downstream oil industry was studied by elaborating a structured questionnaire focused at highlighting different aspects of safety culture and the overall level of risk perceptions of internal and outsourced workers. Results may help in properly using ALARP as a ruling principle in safety management accounting for the human factor and avoiding a static decision-making principle, where the fixed balance between the expected values and the safety concerns cannot be appropriate (Abrahamsen et al., 2017).

2. Methodology

The starting questionnaire was designed by consultation with three experts from management board and the HSE department of the refinery. In designing the questionnaire, an effort was made to cover all aspects of health and indicators and perform a careful assessment of the actual situation, based on data directly collected at the level of operational staff. The questionnaire was developed in a semi-structured interview by adopting, where possible, Likert-type scales, even in drawing and trying to maximize the number of categories based on the item of interest. It was distributed to the workers having familiarity with the hazards, occupational and process safety. The main purpose of questionnaire was intended to gather data on a number of control variables, taking into account personal characteristics of respondents. In order to evidence how firms try to reduce the occupational risk also for temporary employees, two separate questionnaires were developed. Even if essential for the differentiation of the results in relation to the activity/work area, some information were not reported due to a "cautionary interpretation of the law privacy". The questionnaire package was sent to all the workers of the facility, divided into daily and shift workers, having at least one-year experience with a response rate of 77.0 %. Globally, results were obtained from 507 internal workers of the downstream oil plant and 186 outsourced workers. A section of the questionnaire was designed to characterize technical, organizational and individual factors of people experiencing injuries or near misses: the actual number was 71 among internal workers and 13 outsourced workers. Data were further processed by techniques of inferential statistics and ANOVA, in order to show significant correlations between accidents and involvement of human factors. Ideally, the defects of the process safety management can be evidenced and leading metrics to measure the performance of the process safety management can be elaborated.

2.1 Questionnaire evaluation design

The questionnaire was divided in four axes or dimensions for the evaluation, performed on the basis of the answers to "key questions". For each dimension, three items were considered to characterize the workers, as summarized in Table 1. The evaluation of the four dimensions was presented using a radar diagram developed *ad hoc* and structured on three semi-quantitative levels: critic (range 0-1-red), acceptable (range 1-2 yellow) and optimal (range 2-3-green), highlighted by different colours for an immediate visual understanding in Figures 1-4. The most significant results from the evaluation were 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 management of the industry;
- elements of diversion: highlight the main results in statistically significant value, in the range that goes from minor deficiencies to potential problems with the objectives of an effective safety program;
- lines of intervention: early technical/strategic indications, to be integrated in the process safety management plan of the company.

The results of the questionnaires were subjected to statistical analysis (ANOVA) with the aim of recognizing the significant variables affecting plant safety, including if errors attributable to behavioural violations of rules were present, as well as the level of risk perception and safety culture in the organization.

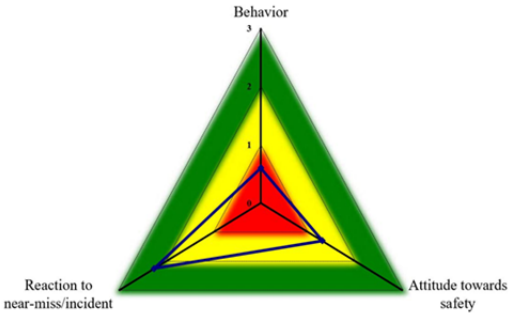

Figure 1: Assessment of Individual Dimension

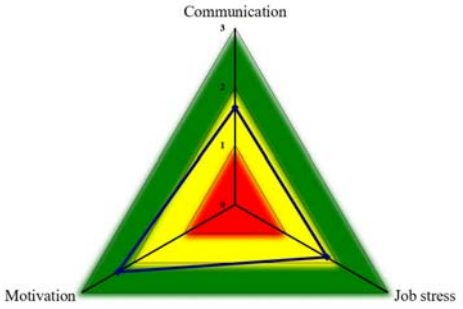

Figure 2: Assessment of Organizational Climate

3. Results and Discussions

As amply reported, knowledge on human aspects has enabled striking advances in productivity, safety and risk control, namely four main reasons can be identified for taking action on human factors (Fabiano et al., 1995):

- evidence that human factors represent a relevant percentage of accident causes;
- need of identifying weakness in the training system and operator safety education;
- awareness of the strategic importance of developing a mature safety culture;
- increased regulatory focus on issues related to human behavior.

In Table 1, main findings of the questionnaires are outlined, referring to the four conceptual dimensions.

Table 1: Items characterizing the four conceptual key dimensions.

A	**Individual**	
A1	Behavior	Constitutes one of the key topics in the field of behavioral dimension and includes every aspect in relation to task execution.
A2	Attitude towards safety	Includes individual factors related to self -safety, consciousness and knowledge of the hazard associated to the process.
A3	Reaction to near-miss/incident	Includes the appropriate actions to anticipate or eliminate the hazard and prevent unsafe conditions or escalation of damage.
B	**Organizational climate**	
B1	Communication	Incorporates the formal and informal communication in relation to plant items, operational, safety personnel and process.
B2	Job stress	Involves aspects related to independence, ambiguity of roles and the production pressure.
B3	Motivation	Characteristics of sensitivity and adhesion of the staff to the strategic guidelines laid down by the company, particularly in the safety field.
C	**Human resources management**	
C1	Procedure	Includes the procedures, permitting and practical application of regulations / safety regulations.
C2	Education and training	Element inherent in all education and training activities.
C3	Accountability	Element tended to identify the degree of accountability and inter-level working group.
D	**Equipment and technologies**	
D1	Working conditions	Refers to conditions of labor objectified by appropriate physical and situational indicators.
D2	Risk prevention and mitigation	Refers to the fixed equipment, addressing both risk prevention and protection, as well as PPE.
D3	Layout and Maintenance	Includes the technical aspects and the preventive and corrective actions in the different plant sections.

3.1 Individual

Individual behavior of the workers was determined by dividing it into three further categories, i.e. behavior, safety attitude and reaction to unwanted events, with quantitative evaluations shown in Figure 1.

- Behavior: results obtained from both internal and outsourced workers showed that, on a formal level, a clear behavioral attitude of respect and attention to the operating procedures for hazards relating to a specific activity was present, accompanied by a proactive operational approach. Data observed from internal workers questionnaire showed that, at least occasionally, 45.3 % of violations took place with the safety standards prescribed in relation to those risks, which were apparently considered less serious or less likely. For example, failure to use PPE was 53.6 %, failure to observe regulations on to vehicular traffic was 60.1 %, high places without climb ladders and application equipment or safety standards was 37.8 %, etc. From the data obtained, it was also observed that daily workers paid less attention to the

general use of PPE (68.1 %) as compared to shift workers (40.9 %). Results obtained from outsourced workers revealed that 61.3 % of workers not always follow safety rules and prescribed procedures.

- Attitude of workers towards safety reflected a good knowledge of emergency procedures, which evidently arises from specific trainings. For internal workers, attitude towards safety was good since 74.7 % of respondents commented about its effectiveness, and 70.2 % of the responses came from persons working in hazardous conditions. The 85.7 % of outsourced workers revealed the awareness of being in potentially hazardous situations. On the other hand, the 74.9 % of internal workers showed a clear conflict between pressure and productive behavior in terms of worker safety. This item is widely reported in the international literature (Fabiano et al., 2010) and is empirically confirmed by this study, being production pressure the main perceived cause of injury, with a percentage of 25.9 %. Alongside the behavioral attitude, there was also a significant tendency to by-pass relevant procedures (66.3 %). Worker perceiving the feeling of being in an unsafe situation were those employed as shift workers (77.0 %), due to increased exposure time to the hazard-specific job. For outsourced workers, safety procedures were also not well known and applied only by 39.5 %. There was also a tendency of by-passing the procedures (56.0 % of respondents).
- Reaction to near-miss/incident: 71.3 % of operational staff of internal workers claimed to be aware of accidents and to know their implications and consequences. Safety procedures were sufficiently known and there was a satisfaction level of 75.1 % in the sample. However, it was observed that the knowledge of the staff about the occurrence of accidents was limited to the immediate causes and it did not extend to the root causes.

3.2 Organizational Climate

Organizational climate plays an important role in judging the involvement of human factors in accidents. It comprises three categories, namely: communication, job stress, and motivation, evaluated as in Figure 2.

- Communication: the 83.4 % of the responses of internal workers indicated good mutual communication and understanding among the people who make up their own operational staff; in addition, a good communication was maintained at the time of shift change. 77.3 % of outsourced workers perceived a satisfactory communication both with internal staff and the company, and highlighted the high level of mutual understanding in performing different tasks (87.0 %). However, 53.3 % of the internal workers reported problems of communication between operational staff and maintenance personnel; according to shift workers sample this percentage rose to 59.0 %.
- Job stress and motivation: significant results were obtained from the answers of internal workers. The harmful effects of workplace injury are significant factors in the perceived stress levels rather than working pressure and hazards inherent to the refinery environment. The level of involvement in issues related to safety proved to be satisfactory overall, with a positive value. For outsourced workers, similar considerations could be developed considering outsourced companies, although the value, in this last case, is to be considered limited to the particular type of sample. For a limited number of internal operators, in some instances, the safety at the operational level was more regarded as compliance with legal requirements.

3.3 Human Resources Management

Human resources management is an important factor for any organization for judging the involvement of human factors in accidents. In this questionnaire, human resources management was evaluated considering three categories, namely: procedures, education/training and accountability. Results are depicted in Figure 3.

- Procedures: for internal workers, results showed a positive response. 72 % of the workers showed positive intent to follow safety related procedures. As mentioned in earlier results, the problem of updating the procedures, and not merely formal compliance, was relevant. 87.4 % of the responses validated, related outsourced workers, showed a formal adherence to procedures for carrying out operations. A cross-analysis between the results of the questionnaire and adverse events or accidents evidenced that numerous procedures were not completely followed, or were completely disregarded, according to the 73.9 % of the responses. The lack of definition of responsibilities in the procedures and the perception of limited clarity of procedures were the main cause of this attitude. Especially daily workers were involved in this failure. 63.2 % of the responses indicated the impossibility of finding a partner for the arising problems, while 73.0 % manifested explicit difficulties in applying certain procedures for the problems. For outsourced workers, as noted above, the procedures relating to personal safety were particularly disregarded and this item may pose an alert on the permitting/procedural system.
- Education and training: in principle, workers owing to a good knowledge of emergency procedures, arising from a basic safety culture, consider the training important. Considering internal workers, only a small

percentage (8.9 %) of the responses showed less sensitivity/interest in training, while 73.7 % of respondents evidenced the effectiveness of training actions. Result was entirely consistent with the sensitivity to safety issues mentioned in the other dimensions. For outsourced workers, 96.8 % of operators followed a course of training in the last two years. The received training was considered satisfactory in 78.8 % of responses.

For internal workers the firm investment and commitment to training was appreciated, even though the perception and effectiveness of the training program was not completely satisfactory. Results from outsourced workers revealed that the training received in relation to emergencies was satisfactory only in the 66.9 % of the responses. In this regard, it should be noted that in presence of a notable number of young temporary workers (age bracket 18–24 years), the level of formation and professional training per se may be not sufficient to replace the direct experience gained directly on-site, given the inherent hazards.

- Accountability: for internal workers, the percentage of recorded events related to absence/inadequate permit to work were rather limited (14.1 %). In fact, based on the analysis of near-miss and accidents PTT events were mainly connected to *outsourced* workers e.g. during preventive programmed maintenance activities. Strategic management should be considered essential, even in the absence of near misses or adverse events, while it is not appreciable a flow of information relating to safety deficiencies in the direction of the operating core. The efficacy and motivation for this flow of information is proportional to the actual findings that the operator receives as a follow up of management periodic surveys on the plant and planned/implemented corrective actions. As remarked, results evidenced that the safety procedures were by-passed in some instances, thus posing an alert for the permission procedure of the outsourced workers.

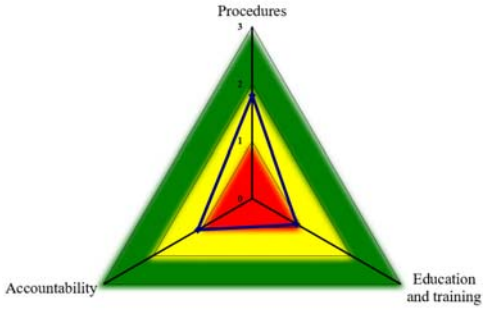

Figure 3: Assessment of Human Resource Management

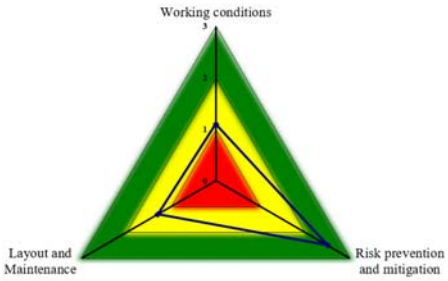

Figure 4: Assessment of Equipment and Technologies

3.4 Equipment and Technologies

Equipment and Technologies play vital role for any organization to judge the involvement of human factors in accidents and according to the developed framework, the topic was further explained under three categories, namely: working condition, protection & risk mitigation and lay out & maintenance (Figure 4).

- Working conditions: for internal workers, all appropriate steps were faced promptly to effectively eliminate the uncomfortable conditions in the working environment, after the elaboration of adverse events recorded in the plant. The 90.7 % of the responses showed the presence of not optimal working conditions, with a percentage of 31.2 % evidencing the high frequency of occurrence. Hazardous deviations connected to work environment included obstacles with possible fall (96.2 %), construction not removed at the end of the work (93.9 %), and lack of adequate lighting (91.3 %). Despite the majority of internal operators perceived the presence of not optimal working conditions and shift workers emphasized a high frequency of occurrence, daily workers indicated them as occasional events. For outsourced workers, 92.3 % of the responses showed the occasional presence of not optimal working conditions.
- Risk prevention and mitigation: internal workers considered PPE available, efficient (91.2 %) and easy to use. Safety signs were perceived as reliable and understandable (74.8 %), in full compliance with current regulations in terms of general guidance and safety programme. Outsourced workers confirmed that PPE were available (90.6 %) and ease of use, safety signs were present and understandable. For construction sites, 81.3 % of the structures did not have adequate protection, as pointed out above by shift workers. Occasionally (33.3 %), safety equipment was in poor condition, as indicated by some adverse recorded events and not perfectly consistent with the procedures (51.7 %).

- Layout and Maintenance: results obtained from the oil plant layout and maintenance section revealed that there were minor gaps in the application of procedures for the inspection and control. They revealed frequent 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/warnings was optimal according to the regulations, even if the need for more immediate and understandable hazard indications of danger in critical hazardous areas of the plant or process steps was perceived by nearly 58 % of the workforce.

4. Conclusions

The approach provided an overview of the most important/urging actions, based on monitoring leading (proactive monitoring) and lagging (reactive monitoring) indicators. Starting from the recognition of the most influencing factors, this study highlighted gaps in the management system that could be remedied and showed which layers of protection require effective implementation in practice for risk prevention or mitigation. Practical actions include the issues of process safety formation, interpretative vigilance, on-plant training, site and group audits, ensuring compliance with established safety procedure and corporate safety culture. Training is of particular importance to refinery personnel in relation to the specific knowledge and process plant; therefore, its execution should be entrusted with experience in the same field. Additionally, the targets set by the HSE policy and consistently oriented according to the approach of "zero accident" should be integrated with an objective indicator of performance improvement on an annual basis. This indicator, to be developed based on a trend line drawn in the short to medium term, may represent annual target of immediate perception suitable to increase staff motivation. A further result is the increasing level of safety awareness of the employees that can be improved by a systematic survey, as the conventional philosophy of making workers responsible for hazard identification and providing proper assessment guidelines may not be sufficient to reduce accident rates.

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