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A METHODOLOGICAL APPROACH FOR ANALYSIS OF HUMAN ERRORS IN THE PRODUCTION SYSTEM

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Abstract. *A complete understanding of the multitude of roles that people play in the work process, as well as factors that influence people's decision-making is crucial for accident prevention and operational efficiency through reduction of risk, elimination of any shortcomings, and successful functioning and maintenance of the production process. The method used to analyze, identify, and reduce human errors is a vital aspect of managing a production system.*

We conducted a study at ArcelorMittal LLC in Zenica, Bosnia and Herzegovina, where the HFACS "Human Factors Analysis and Classification System" approach was applied to identify human errors in accident analysis. The results of this study indicate that the most significant causes of human error and accidents are "preconditions for unsafe acts" (36%), followed by "unsafe supervision" (31%), "unsafe acts" (21%) and"organizational influences" (12%). Based on these results, we concluded that HFACS can be used not only for the identification of human errors but also as a tool for defining corrective measures and reducing human errors.

Key words: *human error, accident, occupational injuries, production system, HFACS.*

1. INTRODUCTION

A review of the literature shows that the "human factor" was the cause of 80% of major accidents in the past (e.g. Chernobyl, Bhopal, Three Mile Island, etc.) and a crucial factor in around 90% of occupational injuries [1]. Management of internal and external human

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factors can reduce the number of injuries and damage to natural and material resources [2]. The success of any organization depends on how well they control the behavior of their employees, while safety managers should be focused on the "human error" as the biggest individual source of operative errors [3].

The common term "Human Error" has been defined by Swain as "a member of a set of human actions that exceed some limit of acceptability, i.e. an out of tolerance action (or failure to act) where the limits of performance are defined by the system" [4]. Human error may be triggered by different factors: insufficient qualifications of an operator, lack of precision, cognitive failure or concentration deficiency, failure to understand and follow rules, etc. [5].

Human Error Analysis (HEA) is the most important part of risk assessment because an important error is overlooked, it will not be considered and the results may significantly underestimate the human error in the analyzed system. To properly conduct a HEA, it is necessary to have good data and adequate processing of information by linking several different databases. Industrial accidents case studies are an ideal source of data on human errors, but gathering this information is difficult due to a number of factors (difficulties in estimating the number of possibilities in which an error could occur in complex tasks, reliability of data, confidentiality or lack of desire to publish data, different causes and mechanisms of error, lack of awareness about the benefits of recording and collecting data, out-of-date data, failure to keep up with workplace demands and ongoing technological innovation, inadequate generalization on experimental data, the time needed to collect the necessary data, etc.) [6, 7].

There are several approaches or models used in the analysis of occupational accidents and human errors, including Rasmussen, Reason, Kirwan, etc. (for more, see [6]). The model that has the greatest application in practice is the "Swiss cheese".

The "Swiss cheese" model, presented by James Reason [8, 9], lists several different causes of accidents. The model itself consists of protective layers between hazards and accidents. According to this model, the cause of an accident is the interaction between latent and active errors. Latent errors concern the organizational arrangement and stem from the top management decisions; as such, they are hidden until they cause an accident or take a long time to uncover. Active errors are the immediate causes of an accident, they are immediately noticed and can be treated as errors of workers who are directly involved in the production process.

Reason's model does not identify the nature of the "cheese hole", nor does it explain in detail the types of active and latent errors, and therefore it is not possible to identify them during accident analysis or, better yet, before an accident occurs. Human Factors Analysis and Classification System (HFACS) overcomes the shortcomings of Reason's model and complements it by precisely defining active and latent errors at all levels of business [10].

The Human Factors Analysis and Classification System (HFACS) is a general framework for identifying the causes of human error, originally developed and tested in the U.S. Army as a tool for investigating and analyzing the causes of aviation accidents. In general, the causes of human error can be internal, leading to the so-called endogenous defects, and external, leading to the so-called exogenous errors. Endogenous errors arise from cognitive processes and are dealt with by psychology and neurology researchers. Exogenous errors are caused by or related to the context in which human activity takes place. Although the cognitive process is also present in these errors, the dominant role is played by the environment and the situation in which the person finds himself/herself. If exogenous errors are caused by inadequate ordering of the system, they are called systemically induced or systemic errors [11]. The Human Factors Analysis and Classification System primarily deals with the causes of exogenous errors.

In this paper, we used the HFACS approach to identify human errors in a case study conducted in the production system of ArcelorMittal LLC in Zenica, Bosnia and Herzegovina, when an accident and occupational injury. A production system is a set of technological systems and other technical, informational, and energy structures, which follow specific procedures to accomplish the set goals of the production process. It contains a multitude of different elements interconnected to form an integrated unit.

ArcelorMittal Zenica LLC specializes in the production and sales of steel billets and rolled steel products (multi-purpose wire rods, ribbed and round rebars as bars and coils, reinforcement mesh panels, lattice girders, and traditional construction reinforcement), made in its coke plant, sinter plant, blast furnace for molten iron, and steel plant, which also generate coal tar, ammonium sulfate, and slag as by-products.

ArcelorMittal Zenica LLC is home to the integrated production of iron, which comprises the primary portion of the metalworking process, specifically the coke plant, ore preparation, agglomeration, and the blast furnace, as well as the secondary portion, involving the steel plant and the rolling mills.

Many operations and processes within the integrated production are classified as jobs with a higher risk of human errors, injury, or illness. They include numerous hazards that warrant a systems approach and the involvement of all employees to ensure safe work conditions.

2. METHODOLOGY

HFACS can be used as a retrospective and as predictive method in human error analysis. HFACS is less used as a retrospective method. There are many more applications of HFACS as a predictive method. HFACS describes four levels of system failure, each corresponding to one of the four layers within the Reason model (Figure 1).

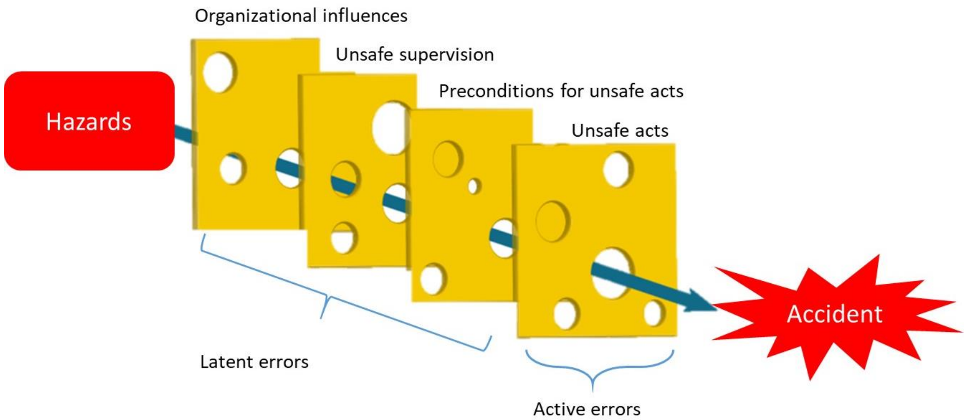

Fig. 1 HFACS approach [12]

2.1. Unsafe acts

Unsafe acts are the first level of system failure, they are active failures made by workers. They are categorized into errors and violations. Errors represent the mental or physical activities of individuals who fail to achieve their intended outcomes. They occur unintentionally and within the rules and regulations of the organization:

- Skill-based errors are the most common errors due to lack of attention which is a result of automated and routine actions: failure to prioritize attention, careless use of equipment, omission of procedural steps, ignoring checklist points, and inadequately assessed situations.
- Decision errors are behaviors that are treated as planned, but the plan itself is inadequate or inappropriate. They consist of procedural errors, bad choices, and errors in solving problems. These mistakes are also called "honest mistakes" because they are the actions of individuals who probably had the best intentions, but did not have the appropriate knowledge or their choices were inadequate.
- Perceptual errors occur when an operator makes decisions based on wrong information because their sensory input is degraded (e.g. as is the case with visual illusions and spatial disorientation).

Violations are intentional non-compliance with rules and regulations. Routine violations are usually bad habits that are often tolerated because it is known that their consequences are not worse than if they were not committed (e.g. some people always drive 5 km/h over the speedlimit and can be said to routinely violate the speed limit, it is their habit). Exceptional violations are not indicators of the typical behavior of an individual and are not tolerated by management. It is important to note that, although most exceptional violations are serious, they are not considered "extraordinary" because of their extreme nature, but because they are not typical for the individual and, as such, cannot be tolerated. What makes exceptional violations extremely dangerous is that they cannot be predicted and it is certain that their consequences are drastically more severe.

2.2. Preconditions for Unsafe Acts

The preconditions for unsafe acts are usually latent failures, but they can also be the initiators of an accident. They consist of environmental factors, the condition of an operator, and personnel factors [10].

Environmental factors can adversely affect the condition of operators, and thus unsafe acts. Broadly, they can be categorized into factors of the physical environment and the technological environment. The physical environment refers to the operational environment, which includes weather, altitude, and terrain, as well as the environment, which includes heat, vibration, lighting, the presence of toxins in the air, etc. The technological environment encompasses several potential issues, including the design of control panel equipment, control panel screen characteristics, checklist layout, and so on.

The condition of an operator can affect the performance at work. Condition of operator refers to the unwanted mental and physiological condition of the operator and physical/mental limitations. Unwanted mental states are those mental states that negatively affect the performance of individuals: loss of consciousness, distraction and mental fatigue due to insomnia or other reasons, excessive or insufficient self-confidence, lack of motivation, and frustration. Adverse physiological conditions refer to those medical or physiological conditions that may affect business security: visual illusions, spatial disorientation, physical fatigue, illness, drug or narcotic effects, etc. Physical/mental limitations refer to those cases where operational requirements exceed the physical and mental capabilities of the individual.

Personnel factors relate to the interaction of personnel who are not directly responsible for performing a particular operation with the operator, and to the impact that such person may have on their unsafe activities. Employee management involves communication and the flow of information that, if inadequate, can result in unsafe acts. Latent failures of this type are lack or inadequate communication, lack of teamwork, lack of reporting, etc. These failures can also appear as active causes of accidents if they manifest themselves as failure to transfer information, non-use of all available resources, confusing or conflicting requirements and directives, etc.

2.3. Unsafe supervision

Unsafe supervision is a latent failure made by the midlevel management (line managers) in the organization. The level of unsafe supervision is divided into four categories: inadequate supervision, planning inappropriate operation, failure to correct the known problem, and supervisory violation.

Inadequate supervision relates to omissions of line managers to ensure that the work is completed safely and efficiently. These omissions can occur in the operational management and supervision, in providing: work guidelines, procedures, training, rest breaks, incentives for employees, etc. Planning inappropriate operations can influence the operational pace and schedule of employees by which individuals are exposed to unacceptable risk. Such jobs, although probably unavoidable in emergencies, are otherwise considered unacceptable. When supervisors are aware of a person's shortcomings, they must take the appropriate actions such as additional training, changes in duties or workplaces, sanctioning, etc. Supervisory violations occur when line managers intentionally disregard existing rules and regulations or do not initiate actions such as: correcting errors in documents, reporting unsafe conditions, initiating corrective measures, etc.

2.4. Organizational influences

Organizational influences refer to latent errors of the highest level of management whose decisions directly affect the supervisory practice, conditions, and procedures of operational staff. These errors often go unnoticed by safety experts, largely due to a lack of a clear research framework. The level of organizational influences is divided into three categories: resource management, organizational climate, organizational (operational) process.

Resource management covers the area of corporate decision-making regarding the allocation and maintenance of organizational resources: staff, cash, equipment, and facilities. Top management can make latent errors that have unforeseeable consequences in decision-making, where there are always two opposing goals: safety and cost. Organizational climate or work atmosphere within an organization refers to a wide range of variables that affect employee performance. The most important elements of the organizational climate are a chain of command, a delegation of power, communication channels, formal responsibility for doing business, culture, and politics of the organization. Organizational (operational) processes are corporate decisions and rules that regulate daily activities within the organization. These include the development and use of standard operating procedures and formal methods to maintain control and balance between workforce and management, risk management, and the development of an adequate safety program.

3. Results and Discussion

HFACS approach was used to identify human errors and analyze occupational injuries at ArcelorMittal Zenica LLC. The analyzed scenario involves the case of routine maintenance of a high-voltage (HV) power facility, specifically a 6.3 kV 2/III load cell installed inside the “Jug” substation, Energy Department, during which severe physical trauma occurred due to electric shock.

An internal investigation of the occupational injury determined that employees from the company's Energy Department performed the planned tasks of inspection and cleaning of the 6.3 kV 2/III load, in accordance with the issued work order. The tasks are considered regular and routine and, according to the internal procedures, they do not require an additional risk assessment, because all risks and hazards are already included in the risk assessment for the positions of assistant substation operator and substation operator (‘switchman’), whose duties include the said tasks [13].

Preparations were made to secure the work location and to ensure safe operations in keeping with the current legislation and the internal codes of ArcelorMittal Zenica LLC. The procedure went as follows [14]:

- a work order was issued, outlining the tasks and designating the crew leader and the crew,
- an order for manipulation in the HV power facility was issued,
- the busbar section disconnector was switched off from the 2/III load cell and the auxiliary power was turned off,
- the 2/III load cell's voltage was checked and it was found that the cell was not live,
- the load cell’s section disconnector was locked,
- busbars were short-circuited to earth using jumpers,
- the substation operator placed the keys to the locked isolation points inside the isolation locks and key storage box,
- the crew members secured the storage box with their personal locks.

After the preparation procedures, the crew leader received permission from the dispatcher to complete the work order and notified the other crew members, who began performing their tasks.

The 2/III cell was originally designed by a company called Energoinvest in 1975. It contains two separate parts – one for the power cell and another for the load cell. In the normal operating mode, the two parts are separated by a protective panel that prevents voltage transfer between the two parts.

On the day of the accident, the 2/III load cell was the item to be worked on, and its power was turned off, as confirmed by a light-emitting indicator. The workers performing the task, who had been employed at the company for 10 months at the time (5 months on low voltage jobs and 5 months on high voltage jobs) performed the task under the supervision of an experienced crew leader – the substation operator, who had been with the company for 12 years. Since the power cell was not to be worked on, it was separated from the 2/III load cell by a protective panel while under a constant voltage of 6.3 kV, in accordance with the procedure. However, the soon-to-be injured worker started removing the protective panel because they did not fully understand what they were supposed to be doing, which triggered unsafe work conditions that resulted in occupational injury. The worker requested assistance from the substation operator, who mistakenly gave it after learning about the protective panel's unique construction.

Nobody verified whether the section busway inside the power cell was live after the protective panel was removed. Intending to clean the HV isolator, the soon-to-be-injured worker touched the section busway at 6.3 kV, receiving an electric shock and severe physical trauma.

Following the accident, an investigation team was formed, which analyzed the current state in the field by gathering facts from the accident site, interviewing the workers, and inspecting the following internal and external documents [15]:

- the permit to enter the HV power facility,
- the work order,
- the order for the manipulation inside the HV power facility,
- work license,
- instructions for the manipulation and provision of no-voltage conditions,
- the single-line diagram, the work order records, and the daily reports,
- the "Isolation and Lockout" procedure of the quality system,
- the reports on safe work knowledge tests,
- the reports of periodical medical examinations of the employees involved in the accident,
- Regulation on Occupational Safety during the Use of Electric Current, "Official Gazette of the Socialist Republic of Bosnia and Herzegovina", no. 34/88,
- Law on Occupational Safety, "Official Gazette of the Socialist Republic of Bosnia and Herzegovina", no. 22/90.

Occupational safety and health management at ArcelorMittal Zenica LLC are regulated, among other things, through the implementation of the corporate Fatality Prevention Standards (FPS). Incident Investigation is one of the more prominent standards, which is implemented in the event of an occupational injury, either severe or fatal [15].

After the investigation team was formed, the investigation of the occupational injury in the "Jug" substation involved the following steps [15]:

- collecting information,
- asking questions and conducting interviews,
- identifying the root causes using Root Cause Analysis (RCA) and Critical Decision Analysis (CDA),
- defining efficient preventive and corrective measures.

The present approach to the analysis of occupational accidents and injuries is based on the abovementioned elements of an accident investigation, whereby human error analysis is seen as a part of critical decision analysis, as an integral part of the investigation, and not as a separate element that requires detailed analysis. In this analysis, special importance was given to collecting information about the accident and conducting individual, structured interviews immediately after the accident. The following employees were interviewed [13]:

- Switchman, leader of the work team appointed to perform the work in which the injury occurred (eyewitness of the accident),
- Switchman associate, member of the work teams (eyewitness of the accident),
- Dispatcher, shift manager,
- Senior supervisor, master electrician, and
- Maintenance manager.

The health condition of the injured worker did not allow for an interview immediately after the accident, so it was conducted after his recovery and complete readiness to discuss the details of the accident. The information gathered by interviewing these individuals greatly helped to understand why the accident occurred and revealed important causes that led to the wrong decision. In addition to interviews, gathering facts from the scene of the accident, observing the actual situation on the ground, and reviewing internal and external documentation led to the following results using the HFACS method (Figure 2).

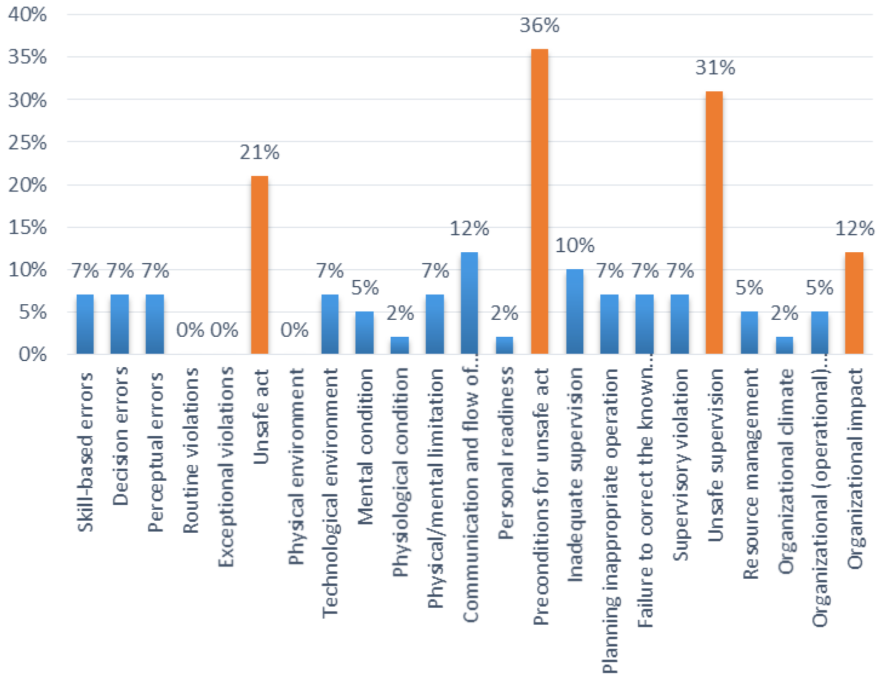

Fig. 2 Causes of human errors in ArcelorMittal Zenica

Based on the obtained results, we can conclude that the largest number of different causes of human error occurs in the category of "preconditions for unsafe acts" (36% of the total number of errors). The most common errors are the following:

- communication and flow of information (lack of teamwork, confusing requirements of task),
- technological environment (power cell design, impossibility of complete shutdown, and isolation of equipment due to the requirements of the production process),
- physical/mental limitations (simultaneous performance of various high-risk work activities, especially by switchman),
- undesireable mental states (lack of motivation and frustration due to the announcement of salary reduction).

A significant number of errors are related to "unsafe supervision" (31%):

- inadequate supervision (lack of supervision of line managers, the necessary guidelines for safe operation are not provided),
- inappropriate operations planned (job requirements exceed the limits of the operators),
- failure to correct the known problem (neglecting the need for additional training),

- supervisory violations (intentional neglect of existing rules and regulations as evidenced primarily by the fact that the work instructions for controlling hazardous energy were not updated on time).

Active errors by direct executors account for 21% of total errors, and include:

- skill-based errors (omission of procedural steps, failure to check busbar faults),
- decision-making errors (insufficient knowledge, jobs considered routine while risks are neglected),
- perceptual errors (failure to recognize part of the power cell under voltage, lack of warning signs).

In addition to these errors, there are fewer errors associated with "organizational impact" (12%), which should not be neglected in this production system, as they are latent errors that can cause injuries with significant consequences.

These errors are related to:

- resource management (inadequate human resource planning and noticeable outflow of labor without the desire to analyze and stop this trend),
- organizational process (lack of good safety programs and promotion of safety culture by the department management where the accident occurred).

Based on the analyzed data, we concluded that the causes of injuries at work are largely identified as latent errors; therefore, adequate corrective measures should be implemented in this area. In addition, the results indicate that active errors significantly contribute to the occurrence of work-related injuries and that their impact should not be neglected in any case.

4. Conclusion

A case study presented through the analysis of serious work-related injury at ArcelorMittal LLC in Zenica, Bosnia and Herzegovina, indicates that the HFACS approach can be used independently from the analysis of other accidents and work-related injuries. The results of using the HFACS method indicate that the largest number of causes of human error is in the category of "preconditions for unsafe act" (36%), then in the category of "unsafe supervision" (31%), followed by the category of "unsafe act" (21 %). The "organizational impact" category (12%), which essentially includes elements that primarily indicate the role of top management in the occurrence of accidents, is in last place.

Based on the research presented in this paper, we can conclude that HFACS is a good methodological approach for the detailed analysis and classification of human errors. The possibility of simple classification of errors leads to easier differentiation of symptoms and causes, as well as faster compliance of employees, which shortens the time required for analysis and identification of human error. In addition, this method requires researchers to be well versed in the work process and system documentation, to gather information from the field before the analysis of human errors. Given that this method relies heavily on interviews as a means of gathering information, researchers in this regard must have developed communication skills. The main disadvantage of the method is the failure to provide a clear visual representation of the relationship between cause and effect. For this reason, the results of the HFACS method can cause confusion and misunderstanding among people who are not directly involved in the accident investigation and who do not know the system well. Based on the above mentioned, we can conclude that this model is adequate for analysis and identification of the causes of human error in all production systems, including ArcelorMittal d.o.o. Zenica. The HFACS approach provides more opportunities for the analysis of a large number of accidents, and the results obtained may indicate the main causes of accidents and injuries to the production system as a whole.

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METODOLOŠKI PRISTUP ZA ANALIZU LJUDSKIH GREŠAKA U PROIZVODNOM SISTEMU

Potpuno razumevanje brojnih uloga koje ljudi imaju u samom radnom procesu i faktora koji utiču na donošenje njihovih odluka od vitalnog je značaja za sprečavanje akcidenata i ostvarenje operativne efikasnosti – smanjenje rizika, otklanjenje nedostataka, uspešno funcionisanje i održavanje proizvodnog procesa. Izbor metoda za analizu, identifikaciju i redukciju ljudskih grešaka predstavlja važan segment upravljanja proizvodnim sistemom.

Za potrebe ovog rada sprovedeno je istraživanje u kompaniji ArcelorMittal d.o.o Zenica, Bosna i Hercegovina pri čemu je za identifikaciju ljudskih grešaka u analizi akcidenta primenjen HFACS *pristup „Analiza i sistem klasifikacije ljudskih faktora“. Rezultati sprovedenog istraživanja jasno ukazuju da se najznačajniji uzroci ljudskih grešaka i akcidenata nalaze u kategoriji „preduslovi za nebezbedne akcije“ (36%), zatim „nebezbedan nadzor“ (31%), „nebezbedne aktivnosti“ (21%) i na poslednjem mestu je kategorija „organizacioni uticaj“ (12%). Na osnovu dobijenih rezultata israživanja došli smo do zaključka da HFACS može da se koristi ne samo za identifikaciju ljudskih grešaka već i kao alat za definisanje korektivnih mera i redukciju ljudskih grešaka.*

Ključne reči: *ljudska greška, akcident, povreda na radu, proizvodni system, HFACS.*