# Analysis of Accidents Involving Machines and Equipment Using the Human Factor Analysis and Classification System Method (HFACS)

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**Abstract.** Brazil is the forth nation in the world that registers more accidents during labor activities, behind only by China, India and Indonesia. The most causes of workers death and mutilations results from accidents involving machines and equipment. The main aim of this article is to discuss and analyze the causal factors that leads to the human error in the accidents involving machinery and equipment that happened in Brazil between 2009 and 2015 using HFACS, which provides the casual factors that will serve as basis to this study, and to contribute to reduce the number of accidents not just in Brazil, but in a worldwide level, and avoid the recurrence of accidents involving machinery and equipment as well. Several HFACS categories appeared frequently: Technological Environment (78,4%), Violations (76,1%), Perceptual Errors (65,6%), Inadequate Supervision (58,1%) and others.

**Keywords:** Human factors · Accident · Machine · Equipment

## 1 Introduction

Brazil is the forth nation in the world that registers more accidents during laboratorial activities, behind only by China, India and Indonesia. Since 2012, economy has suffered a U$ 6,8 billion impacts caused by people who requires leave of absence of work after suffering injuries during their activities. The most causes of workers death and mutilations results from accidents involving machines and equipment. Only between 2011 and 2013, an average of 12 workers were amputated per day because of accidents with machines and equipment in Brazil.

Due to this significant number, people were losing family members or having serious sequels due to work accidents caused by lack or inefficiency of safety in machines and equipment. Despite labor laws and regulatory standards, this fact is still very worrying, which shows that these are still not enough. Measuring losses through accidents involves a complex equation, since a portion of the losses are invisible (such as loss of life, change in the life and work activity of the accident, impacts on family life, and a decrease in the quality of life) which cannot be quantified [1]. However, these losses must and can be prevented. In this context, accident analysis is important


P. M. F. M. Arezes (Ed.): AHFE 2018, AISC 791, pp. 438–444, 2019.
https://doi.org/10.1007/978-3-319-94589-7_43

way to help understand how they happen, identify the contributing factors that led to the accident and propose appropriate measures to prevent further accidents in the future [2]. Accident analysis should follow a method, as this is essential for understanding how the accident occurred [3]. Thus, many methods have been developed and described in the literature in the last decades, mainly motivated by the inability to establish methods that can be applied in all types of socio-technical systems and in different types of accidents.

The article has the objective of analyzing the causal factors of accidents involving machines and equipment in Brazil from 2009 to 2014, using the Analysis Using Human Factors and Classification System (HFACS) method.

### 1.1 The Human Factors Analysis and Classification System (HFACS)

The Human Factors Analysis and Classification System (HFACS) is a taxonomic incident coding system developed for the US Marine Corps aviation sector and for application by practitioners to aid in investigating and analyzing the role of human factors in accidents and incidents [4]. HFACS provides analysts with taxonomies of failure modes across the following four levels: unsafe acts; pre-conditions for unsafe acts; unsafe supervision; and organizational influences [5].

Additionally, the analysts based on the taxonomies presented by HFACS, which works backward from the immediate causal factors, classify the errors and associated causal factors involved an accident [2]. Therefore, the HFACS framework goes beyond the simple identification of what an operator did wrong to provide a clear understanding of the reasons why the error occurred in the first place. In this way, errors are viewed as consequences of system failures, and/or symptoms of deeper systemic problems; not simply the fault of the employee working at the "pointy end of the spear" [6]. Furthermore, the HFACS framework is capable of exploring the possible causes of accidents with different complexities. In recent years, the HFACS framework has been widely introduced into civil aviation and other domains to study human errors in accidents because of its high reliability [7].

The original HFACS framework [4] describes 19 causal categories. While useful as originally designed for aviation, the nomenclature and examples within some of the causal category proved incompatible within the min. Therefore, the original HFACS framework was modified and a new HFACS machine framework was developed. The first of four levels of the HFACS describe the *unsafe acts* committed by operators that led to the accident, classified into two categories of errors and violations. Level 2 factors, *preconditions for unsafe acts,* refers to both active and underlying latent conditions that contribute to the occurrence of unsafe acts. Preconditions for unsafe acts comprise three categories: conditions of operators, environmental factors, and personnel factors. The third level of failure within HFACS, *unsafe supervision,* considers those instances where supervision is either lacking or inappropriate. The final category of failure, *organizational influences,* addresses the fallible decisions made at board and management levels that influence operations at the lower system levels [8].

## 2 Method

### 2.1 Data Source

The accident reports used in this analysis were obtained from databases maintained by Ministry of Labor in the period from 2009 to 2014. The causal factors obtained were classified by industrial activities (for example, construction industry) and by immediate morbidity factor (immediate factor of cause of the accident, such as a machine). The causal factors related to accidents involving machines or equipment, independent of the field of activity, were selected for analysis, which resulted in 150 different causal factors. These 150 causal factors were ranked in descending order of the number of times (frequency) that contributed to the accidents occurring. Those factors that had frequency less than 10 were excluded years, were eliminated because they are of little relevance. Also excluded were causal factors with vague description (e.g., "other environmental factors"), which made it impossible to understand and categorize. There remained 96 causal factors for the analysis object of this study.

### 2.2 Coding Process

Four analysts coded each incident/accident case. The analysts had previously been trained together on the use of the analysis and categorization framework to ensure that they achieved a detailed and accurate understanding of it. This training consisted of seven half-day modules delivered by a human factor expert. The training syllabus included an introduction to the HFACS framework; explanation of the definitions of the four different levels of HFACS; and a further detailed description of the content of the nineteen individual HFACS categories. The presence or absence of each HFACS category was evaluated from the causal factors. Each HFACS category was counted a maximum of one time per case.

Each analyst did the categorization in the HFACS method independently. To verify the reliability of the categorization, the concordance index among the students was calculated. The agreement index used was calculated as proposed by [9]: (number of students who agreed to factor categorization)/(number of students who agreed on the categorization of factor + no of students who disagreed on the categorization of the factor). The concordance index ranges from 0 to 1 or may be displayed as a percentage. A concordance index of 70% was adopted as an acceptable minimum in this study, following the one proposed by [9, 10].

### 2.3 Statistical Analysis

Preliminary assessments of the incident characteristics and HFACS data were performed using frequency counts. The nature of the relations, if any, between each HFACS level with the level immediately above was conducted using the chi-square test. A value of 1 means that one variable perfectly predicts the other, whereas a value of 0 indicates that one variable in no way predicts the other. The lower level categories in the HFACS were designated as being dependent upon the categories at the immediately higher level in the framework, which is congruent with the framework's underlying theoretical assumptions. From a theoretical standpoint, lower levels in the HFACS cannot adversely affect higher levels. Higher levels in the HFACS are deemed to influence (cause) changes at the lower organizational levels, thus going beyond what may be deemed a simple test of co-occurrence between categories. Analyses were conducted using the software package SPSS.

## 3 Finds

### 3.1 Overall Results

When categorizing the 96 accident factors to the HFACS method, we obtained the data given in Table 1. In this categorization, there was 71% agreement among the analysts, which satisfies the rate of at least 70% adopted, according to [9, 10].

**Table 1.** Factors categorized in HFACS

| HFACS Category | Frequency | Percentage |
|---|---|---|
| *Level-1 Unsafe acts* | | |
| Decision errors | 0 | 0 |
| Skill-based errors | 42 | 4.4 |
| Perceptual errors | 687 | 65.6 |
| Routine violations | 798 | 76.1 |
| Exceptional violations | 0 | 0.00 |
| *Level-2 Preconditions for unsafe acts* | | |
| Physical environment | 282 | 26.9 |
| Technological environment | 882 | 78.4 |
| Adverse mental states | 129 | 12.3 |
| Adverse physiological states | 0 | 0.0 |
| Physical/mental states | 0 | 0.0 |
| Crew resource management | 64 | 6.1 |
| Personal readiness | 115 | 11.0 |
| *Level-3 Unsafe supervision* | | |
| Inadequate supervision | 609 | 58.1 |
| Planned inappropriate operations | 571 | 54.5 |
| Failed to correct problem known | 88 | 8.4 |
| Supervisory violations | 466 | 44.5 |
| *Level-4 Organizational influences* | | |
| Resource management | 37 | 3.5 |
| Organizational process | 476 | 45.4 |
| Organizational climate | 122 | 11.6 |

Most of the causal factors were encoded in active errors, preconditions for active errors and unsafe supervision. Not surprisingly, these were identified in more than three quarters of cases. Unsafe acts were identified in 90.5% of cases, preconditions for unsafe acts were associated with 90.3% of cases, while unsafe supervision was identified in 87.1% of cases. Organizational influences were identified in relatively few cases (56%) compared to the other levels.

The most frequent active errors were routine violations (76.1%) and perceptual errors (65.6%). Violations are related to non-compliance with machine handling rules, for example cleaning/regulating/lubricating of machine or equipment in moving. Regarding the perceptual errors, much of this mistake made by the operators is related to a lack of knowledge and training, for example, lack of knowledge about the functioning/state of equipment. Decision errors and exceptional violations were not identified in this study.

The preconditions for errors most commonly involved was the technological environment (78.4%), which normally involves machinery in poor conditions, for example, a system/protection device that is absent/deficient by design and system/machine/equipment poorly designed. The physical environment (26.9%) is related to the organization of space, cleaning and noise disturbances, for example, noise interference and difficulty in circulation. Adverse mental status was present in 12.3% of the accidents, which involved, for example, performance under psychic conditions, or inadequate cognitive and fatigue/waking state. No cases of adverse physical states and physical or mental limitations have been identified.

Supervision failures included inadequate supervision (58.1%), which is often related to oversight of personnel and resources, for example, absence/inadequate of supervision and lack of training. The inadequate planning of the task was present in 54.5% of the accidents, which involved, for example, lack or inadequacy of task risk analysis and poorly designed task. The violation of supervision (44.5%), in this study is related, mainly, to the lack of qualification of the team, for example Appointment of unskilled and inexperienced worker to occupy a job/perform unusual function. The failed to correction problem (8.4%) was identified in only one factor "postponement of neutralization/elimination known risk".

Finally, the organizational influences included the organizational process (45.6%), which had the most recurrent factors: non-existent or inadequate work procedures and lack of or inadequacy of the work permit system. The organizational climate (11.6%), which generally involved communication failures in the company and an increase in pressure for productivity. Resource management (3.5%) was present in the lack of personal protective equipment and poor personal management.

[4, 10] suggested that inadequate top-level decision making can negatively influence staff and practices at the supervisory level, which in turn affects the preconditions and therefore, the subsequent actions of front-line operators. This study provides statistical support for this hypothesis relationship.

Although most of these models emphasize the need to explore the socio-technical components of the system in order to identify the network of factors whose interaction resulted in the accident, most of the company's security professionals are restricted to evidence of non-existence or failures in protection barriers. An analysis that is interrupted at the first or second level doesn't search the true causes of these failures, which restricts the identification of the network of causal factors of the accident, with negative consequences for prevention. And with this, it contributes to the continuation of the simplistic, dichotomous conception about the causal factors of these accidents.

All types of errors within the HFACS taxonomy have been observed in the research reports. However, the analysts found it difficult to relate some causal factors to the categories of the HFACS method. This fact occurred because some factors were not self-explanatory and needed consultation in every report that we did not have. Thus, it is advised the access to all reports for a more reliable application.

The application of the method was valid because it showed the significant correlations that permeate an accident involving machines and equipment. This finding, in addition to the structure's ability to accommodate most of the contributing factors, suggests that the categories of error, although initially developed for aviation, are applicable to incidents and accidents involving machinery and equipment. Most importantly, the HFACS framework seems to be a useful tool for capturing all relevant data from factors that lead to human error. The failures were identified at all levels of structure, providing strong support for an approach to systems that contribute to accidents and the causal causality model of [11].

## 4 Conclusion

The machinery and equipment industry are the key sector in the process of industrialization and economic development of a country, supplying machinery and equipment that transform the conditions of production of agriculture and industry. However, despite all this development the measures for protection of the operator were not efficient.

The analysis provided an understanding, based on the principles of the HFACS method, of how actions and decisions at higher managerial levels influence and result in operator errors. The results show clearly defined, statistically described paths that relate errors at level 1 (operational level) with inadequacies at both immediately adjacent levels and upper in the organization. To significantly reduce the accident rate, these "paths to failure" related to these organizational and human factors should be addressed. This research draws a clear picture that supports the [11] model of active failures resulting from latent organizational conditions.

The results suggest that interventions at HFACS levels 1 and 2 would only have a limited effect on overall safety improvement. For example, shortcomings in the technological environment are associated with subsequent mistakes by perceptual errors (level 1). However, improving only the technological environment will very unlikely to have a major impact on safety unless supervisory processes (level 3) and organizational processes (level 4) are in place to provide such things as proper training, a maintenance program, good planning of the task and a well-defined security policy. These activities require commitment and organizational capability, which can only be offered at the highest levels of management. This study strongly suggests that greater gains in safety benefits could be achieved through segmentation actions in these areas. Subsequently, it's necessary to realize more studies about accidents with machines and equipment, to establish a similar pattern of results found in other countries and cultures.

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