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The mechanical scaling of unstable rocks and work safety in an underground gold mine

O abatimento mecanizado de rochas instáveis e segurança no trabalho em mina subterrânea de ouro

El abatimiento mecanizado de rocas inestables y la seguridad en el trabajo en una mina subterránea de oro

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In recent years, a device called scaler was introduced, aimed to control exposure to the risk of accidents during the activity of elimination of "choco". The objectives of this article are to analyze the advantages and limitations of the mechanized technology for elimination of unstable rocks; to identify the difficulties and the risks for the operators and the strategies used in the execution of this activity. A qualitative approach was used, combining documental analysis and interviews with six workers during four collective sessions, using a script as a guide. The use of the scaler has brought benefits to the safety and has also minimized the physical effort required by the activity. Organizational factors and the design of the equipment worsen the situation, since the latter does not take into account the physical and psychological characteristics of the operators, neither does the management involved in the activity.
Descriptors: Mining; Occupational health; Accident prevention.

Nos últimos anos, a introdução de um equipamento chamado de scaler buscou controlar a exposição ao risco de acidentes durante a atividade de abatimento de "choco". Os objetivos deste artigo são analisar as vantagens e limitações da tecnologia de abatimento mecanizado de rochas instáveis; identificar as dificuldades e os riscos para os operadores e as estratégias utilizadas no desempenho da atividade. Realizou-se pesquisa qualitativa, combinando análise documental e entrevistas com seis trabalhadores durante quatro sessões coletivas, utilizando roteiro prévio. O uso do scaler trouxe benefícios para a segurança e minimizou o esforço físico necessário na atividade. Fatores organizacionais e a concepção do equipamento agravam a situação, uma vez que não levam em conta as características físicas e psicológicas dos operadores e a gestão implicada na atividade.
Descritores: Mineração; Saúde do trabalhador; Prevenção de acidentes.

En los últimos años, la introducción de un equipamiento llamado *scaler* buscó controlar la exposición al riesgo de accidentes durante la actividad de abatimiento de "choco". Los objetivos de este artículo son analizar las ventajas y limitaciones de la tecnología de abatimiento mecanizado de rocas inestables; identificar las dificultades y los riesgos para los operadores y las estrategias utilizadas en el desempeño de la actividad. Se realizó una investigación cualitativa, combinando análisis documental y entrevistas con seis trabajadores durante cuatro sesiones colectivas, utilizando guión previo. El uso del *scaler* trajo beneficios para la seguridad y minimizó el esfuerzo físico necesario en la actividad. Factores organizacionales y la concepción del equipamiento agravan la situación, dado que no tienen en cuenta las características físicas y psicológicas de los operadores y la gestión implicada en la actividad.
Descriptores: Minería; Salud laboral; Prevención de acidentes.

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INTRODUCTION

The mining industry shows a high rate of mortality related to accidents at work[1-4]. Such accidents are caused by many factors, such as gas or dust explosions, problems related to electricity, falls of rocks from the ceilings and walls of the underground galleries of the mines[5]. These accidents can cause injuries, disabilities, death and suffering, and can also lead to equipment breakages, interruption of operations and increased expenses because of production and social losses[6,7].

In gold mines, the prevalence of mortality related to rock falls is three times higher than in the general average of the sector[8]. In 1995, there were 2,068 incidents and 198 deaths of this type in gold and platinum mines in South Africa. It was the first cause of death in the mines in South Africa, from 1996 to 2005. In 1999, 62.6% of the total of fatal accidents (n=107) in the industry of gold mining were caused by rock falls[9].

In the United States of America (USA), in 1999, the mortality rate was 20 times higher in underground mines when compared to industrial sectors. Almost 75% of deaths are due to the fall of rocks on workers, from the ceiling or the walls of the galleries. Between 1996 and 1998, in the USA, there were 256 fatal accidents in the mining sector, and of these, 45 were caused by rock falls[10].

To improve security in the mines, operators identify unstable rocks — informally known as "chocos" — before they start the work. Once the "chocos" are identified on the ceilings and the walls of the galleries in underground mines, they must be removed (eliminated), using, in most mines, a metal lever. The name "choco" comes from the fact that the sound produced by the unstable rocks when the metal lever is used is a "choco" sound, revealing that, that portion of the rock is detached from the mass of solid rock and, therefore, has a chance of falling on workers or machinery and equipment[11].

These operators, that identify and eliminate "chocos" work in a situation of risk. Between 1984 and 1994, in the USA underground limestone mines, of the total of 201 accidents recorded during control activities of rock mass, about one-third was related to the activities of elimination of "chocos". These accidents resulted in 11 deaths, including one operator working on the mechanized elimination of rocks with a *scaler*[11].

The *scaler* is a large equipment that moves using tires and has a telescopic mechanical arm to eliminate rocks, which can extend for up to nine meters, enabling the operator to remain distant from the location of the "choco" being eliminated.

In recent years, the introduction of the *scaler* was an innovation that aimed to control the risk of exposure to accidents during the activity of elimination of "chocos". The use of the new technology allowed, in mines with wider galleries, to advance productivity, while also improving safety, since the operator is protected in the interior of the cabine[12], as illustrated in Image 1.

Image 1. Illustrative photo of the cabin and the operator of the *scaler.*

This study aims to: analyze the advantages and limitations of the technology of mechanized elimination of unstable rocks, as well as to identify the difficulties and the risks for the operators of mechanical equipment and the strategies used in the execution of this activity.

METHOD

The study was conducted during 2006 and 2007, using a qualitative approach, combining a documental analysis with interviews with groups of workers involved in the task of eliminating "chocos", in a gold underground mine 800 meters deep, 840 employees and located in Minas Gerais, Brazil.

The criteria for the selection of the participants were: being active workers in "choco" elimination at the time of the research and accepting to participate in the research.

Interviews were carried out considering, instead of guiding questions, guiding topics of interest, like: a) a description of the work; b) the occurrence of unexpected events during the task; c) the encounter and identification of unstable rocks; d) accidents experienced; e) the work with the *scaler* and manual elimination. Depending on the content of the statements collected, the interviewers formulated new questions during the dialogue.

The interviews were conducted in four sessions (one per week), for a period of 29 days during 2007. They were recorded only after the signing of the term of free and informed consent that ensured anonymity. The total duration of the interviews was 308 minutes, each lasting between 60 and 97 minutes.

Aiming to stimulate discussion with the group of operators, the critical incident technique was used[13]. Participants were requested to describe the incidents related to unsatisfactory results or to accidents. The workers were encouraged to explain positive or successful events and to avoid focusing on problems or critical situations that are expected in situations of technological innovations, because a theme as the technological change should not necessarily be reduced to its problematic aspects[14].

A qualitative analysis of the content of the interviews was carried out, resulting in the construction of a chart of analytical categories[15]. This analysis allowed for the description of specific properties of security methods and the group of relations involving the work with the *scaler.*

The analysis of the material occurred in a process of back-and-forth. Thus, the study of the interviews went through a spiral process, in which the researchers worked with the material in multiple steps that followed one another. The ethical aspects of the study were respected trough the approval of the project by the Research Ethics Committee of the Universidade Federal de Minas Gerais (ETIC 31/07).

RESULTS

Of the universe of forty-one workers involved in the task of manually or mechanically eliminating "chocos", the final sample consisted of six workers. Table 1 presents the characteristics of the selected operators.

Table 1. Workers in the gold underground mine according to age, length of service and function. Minas Gerais, 2007.

Age	Time in the company	Current function
OP1 - 39 years	7 years	Scaler operator
OP2 - 39 years	15 years and 6 months	Scaler operator
OP3 - 39 years	6 years and 9 months	Scaler operator
OP4 - 30 years	1 year and 2 months	Scaler assistant
OP5 - 34 years	1 year and 6 months	Manual elimination
OP6 - 24 years	11 months	Manual elimination assistant

The categories presented are: *Intrinsic Factors*; *The introduction of technology and the limits of the scaler; Extrinsic Factors: the introduction of the scaler; Extrinsic Factors: the operational standards and risk factors; and Extrinsic Factors: the maintenance of the scaler.*

Intrinsic Factors

For operators, the process of mechanized elimination of "choco' with a *scaler,* if compared to the process of manual elimination, is better against the risks of fragments of rocks falling:

"compared [to] manually hitting the 'choco' , it is much better... Because manually the risk is greater, people... I myself have had a stone fall in the cabin already... if the cabin did not exist I'd not be here... [the cabin] protects" (OP. 2).

In addition, the *scaler* would require less physical effort, because, in the case of the manual elimination, operators handle long and heavy metal braces to reach distant and higher points of the galleries:

It is a risk [of falling rocks] and the physical effort (OP 3).

Generally, the manual sanitation is very tiring, yes" (OP.5,).

The introduction of technology and the limits of the scaler

Specific sound signals (a kind of popping noise) indicates the instability and its effects, such as fractures or falls. In addition to the auditory perception, the work calls for visual abilities to identify the existence of "chocos" after the stabilization of the rock mass, but the visual depends on proper lighting to identify the rocks that need to be eliminated.

The sources of illumination are the headlights installed in the *scaler,* and the flashlight of the operator assistant. The assistants keep the area wet to reduce dust and they also signal the presence of "chocos" trough a special flashlight connected to the *scaler*. The operators recognize the role of the assistant in the execution of their task:

Even with these headlights, it [scaler] usually has a few blind spots...(OP3)

I don't have a complete peripheral vision. Because who has a peripheral vision is the assistant, because there are things that I see that he doesn't see, understand? And vice-versa (OP1).

The robustness and size of the equipment have as a disadvantage the slowness of their movements, with a reduction of the effectiveness of the operation of elimination of rocks and a delay in the reaching of production goals, as observed in the speech of an operator:

The scaler is a good machine ... but is a slow-moving equipment...it is a robust equipment and there are certain points in which it greatly jeopardizes a perfect sanitation, right? (OP3).

Depending on the manufacturer of the equipment (Dux® or Gatman®), the operator faces new situations. For example, one of the models of *scaler* generates a greater heat in the cabin, as pointed out by a professional:

When you take the Gatman you work with the door open... heats up a lot. OP1.

Because it is lighter, the Gatman® scaler does not guarantee cabin stability in cases of elimination of bulkier and heavier rocks and in this case they can impact in the operator's body:

You take too much yanking in the back...the impact that you receive at the time the stone descends...it is as if we hit a car... (OP1).

Extrinsic Factors: the introduction of the scaler

Despite the protection from the risks, the work at the mine with the *scaler* does not eliminate the damage on the body and the uneasiness present in the daily lives of the operators, as can be observed in the speeches below:

The discomfort also comes after when we go down from it...your legs are burning (emphasis) too much... and headache...(OP3).

Extrinsic Factors: the operational standards and risk factors

The prescribed distance narrows the visual field of the operator and may decrease the ability to identify the unstable rocks, especially those of small dimensions. One of the operators, citing one of the areas of work reports that:

There, there is no way to position yourself at 20 meters. You have to stop, look more or less as it will be, many times you have to position the scaler going up the terrain and then back. You have to do this maneuver, you know? (OP1).

With each day of work, the operators are assigned to work in different locations, requiring them to know the conditions of the mine in a number of different fronts. Operators adopt different procedures and intensify the level of attention when they start work in an unknown area. Referring to a particular type of rock mass, an operator emphasizes:

...there, because I have to get more attentive... because the quartz pops a lot... doesn't hold anything. (OP3).

Aiming at a greater knowledge about the process and the transformations of the rock mass, operators seek this information with the other technicians to plan and execute the task with safety. Employees evaluate their actions and achieved results subsequently to the events. For the operator 1:

means a lot the person that has a lot of experience and good will to learn things, right? And to gain experience. Each day we're learning things. I don't say that I know everything, no, I'm learning still, understand?

Extrinsic Factors: the maintenance of the scaler

The environment conditions are associated with the wearing of the workers, but also of the equipment:

In the end it ends up with the machine (OP1).

And with the operator; and increases the frequency of crashes and stops for corrections (OP4).

For operators: *the scaler:*

When it arrives new, it"s wonderful when it arrives, a new one arrives... our problem is, maybe they didn't want to say, it's the maintenance...the maintenance is not adequate (OP2).

This reinforces the importance of a proper maintenance of the *scalers* for the implementation of an effective operation and production:

When you have a proper maintenance it does not slow down, it gets stronger (OP2).

DISCUSSION

The task of eliminating unstable rocks with the use of mechanized equipment reduces the physical efforts and the risk of accidents with falling rocks. However, the accidents have not been eliminated because of a series of factors associated to organizational conditions and environmental factors, and also due to the variability of the rock mass.

The archive of the Brazilian Ministry of Labor and Employment, about information of the state of Minas Gerais, identified in the period from 2000 to 2004, that in a single company of underground gold mining, 285 accidents were recorded (annual average of 57 accidents). Of these accidents, three resulted in death. 64 accidents were attributed to the fall of "chocos" (22.4%), and among these accidents, there were two deaths[11].

Between 2007 and 2009, the incidence of work accidents in the Brazilian mining sector had an average 53% higher than in the other economic sectors [16,17].

In 2000 to 2012, the data presented in 101 reports of accidents in the mining sector prepared by the Regional Superintendence of Labor of Minas Gerais, reported that 79.2% of them were fatal. As to the type of accidents, the impacts caused by drops and falls of rock structures occupied the second place among the causes of accidents (17.8%)[18].

Despite the underreporting of occupational accidents in Brazil[19], the mining sector, from 1999 to 2009, recorded rates of mortality (number of deaths/number of jobs in the economic sector X 100,000) of 58.70 to 28.96, while the national rates were from 20.03 to 7.58[17].

Referring to the intrinsic and extrinsic factors, Figure 2 illustrates a synthetic model, a line of interpretation of the observed results, of where these factors may be involved in the activity of mechanized elimination of rocks.

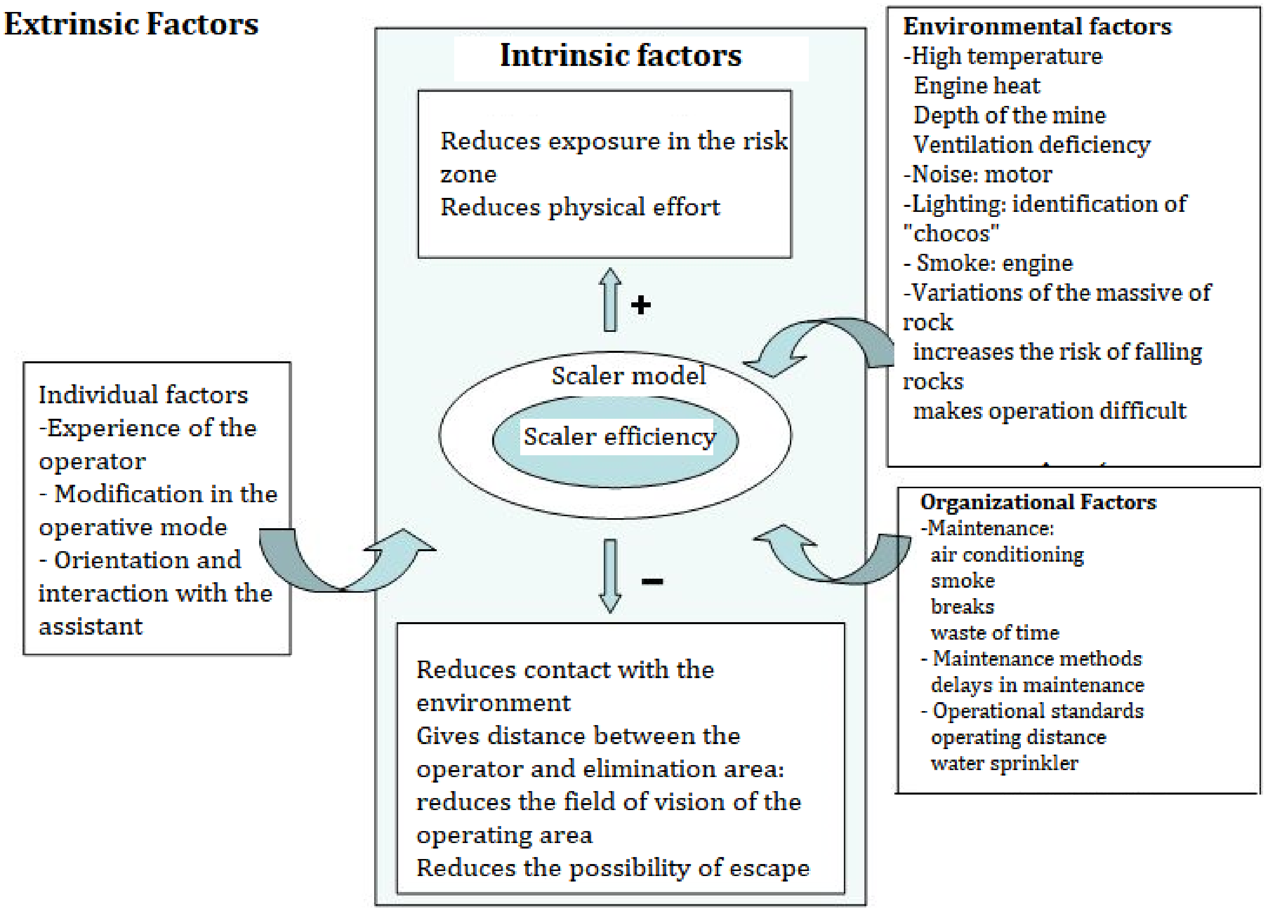

Image 2: Schematic image of the intrinsic and extrinsic factors associated with the effectiveness of the *scaler* in the prevention of accidents in an underground mine.

By having a mechanical arm operated by a hydraulic system in replacement to the stems, the *scaler* allows the operator to stay away from the area where the elimination of "chocos" is happening.

However, the benefits of the *scaler* depend on the type of areas where it is placed. The operators mention the fall of large blocks of rock on the equipment, and that it does not resist serious impacts on its parts or components.

Low illumination is aggravated by the *design* of the cabin, where the field of vision is limited. The operators and their assistants are guided by light or by sound signals, when the radio is available, sharing movements and aiming to achieve a better position for the mechanical arm. The basic signals are standardized, well known and respected by all.

The operators emphasize, once more, the importance of the assistant, especially in the identification and signaling of risks and the need to leave the premises in case of an emergency.

The operators pay attention to the direction of the luminous flux. Ambiguous signs generate impasses on decisions, because the operator may also not see the light signal sent by a colleague.

To improve the lighting and humidify the work fronts, the assistants move in the vicinity of the *scaler.* Because of this, they cause random movements of the flashlight that are not related to a specific signal. Considering this reality, more attention is required during the operations.

The small space inside the cabin can make it difficult to scape, in cases of imminent risk of collapse or falling of the rocks. This restriction is aggravated by the use of the safety equipment.

In summation, the use of mechanized elimination is a safety measure that generates zones that lack safety, because the size of the cabin and its "slowness", together with the positioning of its control handles (pedals, steering wheel, levers, and others) may create difficulties during situations of escape.

A *scaler* with a percussion system in substitution of the lever, is more comfortable, however, when the rock produces more instability when stricken and generates more "chocos". For this reason, it was abandoned.

During their activity, the operators of the *scaler* are exposed to dust, high temperatures, noises and gases from engine exhaust and faces the crashes of equipment, the wear of parts, and the deficient maintenance.

The sprinkling of water on the rocks is not enough to eliminate the dust from arising because of the elimination of "choco", leaving the workers exposed to this risk factor.

To explain the discomfort in the mine, adding to the dust exposure there is also the high temperature of deeper areas where ventilation is more restricted. The running of the motor and the pump of the scaler hydraulic system of the *scaler* exacerbate the harmful effects of the environment.

Another factor that contributes to the heat discomfort is the improper operation of the air conditioning system of the *scaler* cabin. In this situation, the measures to decrease the effects of this micro-climate are extreme: taking out the uniform or let the door of the equipment open, in an attempt to minimize the discomfort and the intense sweating.

Exposure to noise coming from the engine of the *scaler,* similar to the exposure to high temperatures, is a cause of negative feelings.

The company establishes work standards that must be fulfilled by the workers during the elimination of "chocos", among which the already mentioned sprinkling of water on rock masses and on the mineral extracted. The operators report that the sprinkling of water during elimination of "chocos" interferes with the visual perception of the irregularities or cracks in the rocks, which are important evidences for the more experienced professionals, of instabilities in the mine and of the risk of falling rocks.

The sprinkling of water, by provoking a thermal shock on the rock mass increases the frequency of "crackles" and disturbs the perception, because as you make the ceiling wet, the ore crackles, and you do not know if the crack is the sound of rocks accommodating or a "choco" about to fall.

Among the factors that give complexity to the task of "choco" elimination, there are also the different behaviors of the rock being mined. In addition to suffering the influence of the detonations, it can show changes in its structure due to the different types of rock that make the various mineral bodies.

The wear of the equipment and the difficulties of maintenance cause problems such as leaks in the hydraulic system that lead to the reduction of the power of the lever and consequent loss of effectiveness in the elimination of "choco".

The rules of the company require the authorization of the hierarchy to stop the work and move the equipment to the workshop located on the surface of the mine when there are more serious defects or malfunctions. Operators criticize these standards because of their lack of autonomy to solve these problems, which lead to delays.

In face of these difficulties in obtaining the presence of the maintenance mechanics and in an attempt to work around the difficulties that arise from defects, the operators take the initiative of carrying out repairs in the underground. Furthermore, the initiatives of the operators to repair any breakage go against the norms of production and are not recognized by the hierarchy, which generates conflicts between operators and managers.

In this setting of unexpected events, difficulty and danger, the workers of the mine express ambiguous feelings about admission and denial regarding fear. In a situation of risk, the worker has the ability to distinguish dangerous and not dangerous situations that, despite how they look, are not dangerous[19].

The mechanisms that seek to increase the security level can produce new risks and new types of accidents. There was a reduction in the number of accidents related to explosions of methane gas after introduction of the Davy lamp in British coal mines, but there was a concomitant increase in the number of accidents caused by landslides of rocks in the deepest areas[20].

The use of the *scaler* is only possible in broader galleries and large bodies of minerals, making it viable to dismantle larger volumes of rock through the use of larger quantities of explosives. These situations are known for being dangerous due to the displacement and falling of blocks of rock.

The interviewed operators quote the slowness and difficulty of moving the equipment during the elimination of "choco". The *scaler* offers a good level of security for the work, but, due to their size and weight, changes in direction and positioning are difficult and require additional efforts.

The operators are aware of the limitations in the interaction with the environment, which is considered essential to the individual management of risk. The characteristics of the *scaler* cabin reduce the ecological security and cause disturbances in the identification of unstable rocks. The visual field of the operators is restricted when working in the interior of the cabin. These facts are similar to a study about accidents related to fall of trees[21].

As for the different types of *scaler* available in the market, it was reported that the use of a particular model in gold mining has led to the appearance of new "chocos" during their elimination, which explains the increasing in manual work in the course of the process[12].

The data collected from the interviews indicate that the situation is kept under control through an active effort of the workers to correct deviations and dysfunctions, as illustrated by the example of sprinkling water in distant points from the equipment.

In a commitment to obtain a solution for the difficulties presented during work, the operators keep the situation under control, in a process that is described as a dynamic way to manage the activities[22]. The adjustment of the operation time to increase the security after sprinkling water is a procedure different from the one standardized by the hierarchy but is a way to minimize the difficulties and obstacles encountered during the work, while also helping in the pursuit of efficiency and security in the task.

Wetting the rock, to reduce dust, makes it more difficult to see the signs of falling rocks. This paradox is the basis of the elaboration of fine operative strategies by the operators in association with the assistant, which allow for the development of skills and types of operations that facilitate the work and increase safety. When the operator changes the way in which they sprinkle water on the start of the work to reduce the difficulties of perception of evidences of falling rocks, they use the ability called by the literature "sixth sense" or "sense of mining"[20].

The results presented by this study are similar to other studies about the role of the work organization in the development of safer operation models[23,24]. This study made possible to see that operators try to meet the established goals, relying on informal networks of knowledge from other professionals or sectors of work.

The informal networks allow for the sharing of actions and their effects, highlighting the necessary level of cooperation for its execution in a productive and safe way[23].

CONCLUSION

The operators of *scalers* and their assistants are under a set of difficulties determined by environmental factors. The difficulties may be aggravated by the norms of the organization.

The operators revealed knowing the risks and the latent threats in their activities. A greater security on the job could be achieved in an organizational environment less inflexible, considering the relevance of the workers in the search for the solution of problems found in the work, and also valuing to their intuition and experience, as opposed to using measures that only strive for the enforcement of safety engineering standards or legislation.

The workers also adapt their actions to the real conditions found during work, the situations of the environment and the context of work, which are not explicit in the formal procedures, to achieve goals of production with safety. The results of the interviews indicate that a considerable part of the initiatives are carried out by the workers and not by the hierarchical structures, in spite of management directions.

Finally, new types of accidents can be explained when prevention methods and interventions that are considered safe do not incorporate a dynamic approach to the environment and the social relations.

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CONTRIBUTIONS
Mario Parreiras de Faria conducted the collection, analysis, interpretation of data and development of the first version of the article. **Ada Ávila Assunção** assited in the study design, analysis and interpretation of data and critical analysis of the article.

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