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A CASE STUDY FROM BRAZIL OF WORK SAFETY ANALYSIS OF ELECTRIC POWER SYSTEMS

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ABSTRACT: The risks associated with working in the energy sector are: electrical risks, falls, and occupational risks. Describe the risks in the electricity sector, particularly through with data of an electric power company in Northeast Brazil. These data were acquired through accidents internal reporting which resulted in a total of 546 events. Variables such as worker age, day of week, month, and hour of occurrence were analyzed. In terms of worker age, the highest incidence of accidents (74%) occurs with more experienced workers in the company, specifically in those workers 41 to 60 years of age. An increase in the amount of days lost due to accident is related to an increase in the age of the worker. Using a statistical model the influence of worker age (WA) and working time (WT) in the behavior of the dependent variable of days absent (DA) were determined.

Keywords: Work Risk Analysis; Electric safety; Safety Data Statistical Model.

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1. INTRODUCTION

A work accident is an accident that happens by the exercise of work for a company, or by the exercise of the special work of the insured, which causes injury or functional disorder resulting in death or in lost or reduced capacity for work, permanent or temporary. Work accidents also include those accidents that happen between home and the workplace of the insured, accidents understood or triggered by the exercise of work peculiar to a particular activity, and occupational disease acquired or activated while performing functions in special conditions under which the work is done and to which it relates directly (CASTRO, 2007). Work accidents can be classified as follows:

- Typical: occurring due to the features of the professional activity performed by the insured;
- Work way: occurring between home and the workplace;
- Occupational or job illness: produced or triggered by the exercise of work or by occupational disease, activated according to special conditions under which the work is performed and to which it relates directly.

In trying to explain an accident the workers usually try to focus on the circumstances in which it occurred while the supervisors tend to blame the employees suggesting that they deviate from the standard routine of work causing the accident (NIZA et al., 2008).

The work accident is defined as an occurrence beyond expectations with resulting occupational injuries, fatal or nonfatal (HAMALAINEN, 2009). It is something unexpected and unusual and unintended which just happens with no obvious causes (PATWARY et al., 2011). There are two different views about the work accident; the first includes all events with or without damage to the worker (SALDANA et al., 2003), the second considers only those who cause damage and accidents at work

The new millennium is considered one of the aging work forces (PRANSKY et al., 2005). This is an issue of particular concern among researchers due to the increased risk of accidents with consequences such as decreased cognitive function. In research conducted in Sweden, Quebec and France indicate one relationship between the worker age and the days absent due to accident (BENJAMIN et.al., 2000 and CHAU et a., 2002).

The knowledge of quasi accidents provides information leading to the identification of deficiencies in the organization and indicates the control measures to be made. These actions contribute to reducing the likelihood of real accidents occurring in the future (VAN DER SCHAAF et. al., 2004). Quasi accidents are signs of possible accidents and are precursors of future accidents and could be defined by indicators of potential accidents (JONES et. al. 1999 and BRAZIER, 1994).

An important variable in relation to work safety is the worker experience in the task. There are workers who perform their activities recently and due to very little experience have higher risks of getting involved in accidents. This causes financial losses and long-term consequences for the company (BRESLIN et al., 2006 and SIOW et al., 2011). Another very important variable in work safety today is worker mental health. It is estimated are that 20% of workers in the European Union believe that work-related stress is a risk to their health (IDRISH et al., 2012). In Australia, around 7% of the workforce workers suffers from clinical level depression, and stress related absenteeism is estimated to cost the Australian economy $14.8 billion per year.

Work safety studies must be done integrated with the health, safety and environment in single management systems, HSE management (DUIJIMA et al., 2008). HSE management would benefit greatly from guidance on how to use existing management systems more efficiently and also how to further develop meaningful safety performance indicators that identify the conditions prior to accidents and incidents.This paper aims to describe work safety data analysis of electric power systems particularly through the data analysis of an electric power company in northeast Brazil.

2. WORK SAFETY IN THE ELECTRIC POWER SYSTEM

The workplace accidents in the electricity sector assume greater importance due to the magnitude of the consequences that may arise in the event of any occurrence among people or facilities associated with the electric power system (CASTRO, 2007). This sector is characterized by a set of processes, tools, and equipment aimed at the generation, transmission, distribution, and sale of electricity, and has fundamental importance in relation to the development of a country’s economy. It is marked by the presence of significant physical and mental demands, and the dangers and risks to health and safety are considered high. Specifically, work in a power substation can become extremely complex, since the worker is subject to a high degree of uncertainty and has to consider numerous variables. The greatest risk to the safety and health of workers is the source of electricity, since electricity is an agent of high potential risk to humans. Even at low voltages it represents danger to physical and occupational health. Its action is more damaging with the occurrence of electric shock, which leads to direct and indirect consequences (falls, car crash, burns, and other indirect consequences) (BLIGÅRD et al., 2012 and VITORIO et al., 2012).

There were many researches analyzing accidents data in the energy sector where even with all the care and training procedures, fatal accidents occur (BATRA et al., 2001 and BATRA et al., 2001a). In 48% of cases workers were not following established safe work procedure and 24% were not wearing personal protective equipment. Since, electric power is the most commonly used form of energy and is an important part of everyday life, the violation of the rules of use of electricity implies material damages, human injuries, and, unfortunately, very often, loss of life. According to international statistics, electric accidents are the most fatal among accidents.

2.1 Risk factors and accident index in Brazil's electric power system

The risk factors of accidents in the electric power system are as follows:

- Hazards of an electric nature, such as electric shock, electric arc, and electromagnetic field.
- Risk of falling. Falls are major accidents in the electric power sector, occurring as a result of electric shock from the improper use of lifting equipment (ladders, baskets, and platforms), lack or inadequate use the individual protective equipment, lack of training, lack of demarcation and signaling of the bed of the service, and insect attack.
- Risks in transport and equipment. These are the risks involving the transport of workers and the displacement with service vehicles and equipment use. They involve the use of one-way vehicles in the field, and the use of two vehicles and equipment for lifting loads and basket carriers.
- Risk of insect attack. While workers are performing services on towers, poles, and substations, and while meter reading and tree pruning, insects such as bees and ants

can attack. The employee must pay attention to the possibility of bites from venomous animals, such as poisonous snakes, spiders, and scorpions, to bites from dogs as well.

- Occupational risks. Occupational hazards are the existing agents in the workplace that are capable of causing damage to the health of employees.

Figure 1 shows the historical accident rates for Brazil’s electric power system from 1977 to 2010. There was a large reduction in accident rates of the last thirty years. The reduction of these accidents occurred due to the efforts of electric company’s management, and monitoring work of the professionals working in the area. It is noteworthy that during this period there was a restructuring of the electricity sector in Brazil with the fusion and creation of new businesses and new regulatory agent with the ability to penalize, to monitor work and issue sanctions and penalties.

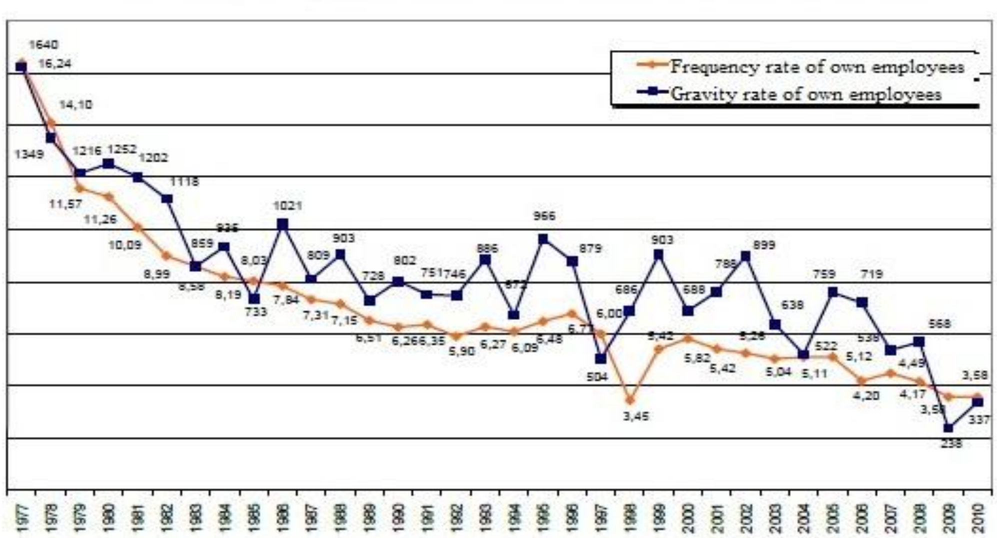

Figure 1 - Accident index, frequency rate and the gravity rate of Brazil’s electric power system from 1977 to 2010 Source: [28]

2.2 Risk assessment activity of the electric power system

The main activities in electric power systems are grouped into two areas: maintenance and operation. A routine procedure in the area of operation involves receiving information such as the conditions of the power system, expressed as electrical values. Other activities are maneuvering in equipment and transmission lines, regulation of electrical variables, system performance, and restoration of the electricity supply. A routine procedure in the area of maintenance involves receiving information to make corrective and preventive maintenance**.**

2.2.1 Maintenance activity

High-voltage transmission is maintained by teams composed of a supervisor or coordinator, driver and Truck operator, aides or assistants, and electricians. Electricians who work in hot-line activities work exclusively with the energized system, isolating it for the maintenance and emergency electricians provided by the concessionaire or who are outsourced for light repairs. The offset to the location of services is done using the truck, and access to facilities by air is undertaken using isolated baskets. De-energized line-pattern electricians conduct inspection activities, minor repairs, and emergency work along the power system. If the normalization depends on repairs that require tools and heavy equipment, the teams of contractors are activated.

In performing maintenance task a preliminary risk analysis (PRA) is made. The PRA is a method of preliminary study and summary of risks, usually conducted in conjunction with the group of exposed workers, with the aim of identifying potential accidents that are most relevant to the task and the intrinsic characteristics. It is a method of studying the risks involved during the planning phase and the development of a particular process, task, or industrial plant, in order to predict and prevent risks of accidents that may occur during the operational phase of the task. Table 1 shows a typical PRA for one maintenance task.

Table 1 - Example of preliminary risk analysis for one maintenance task

PRELIMINARY RISK ANALYSIS						
MAINTENANCE TASK TYPE: INSTALLATION OF A CABLE TYPE "SAPHENOUS"						
Action (in the activity of...)	Risk (can happen...)	Consequence (bringing the effect ...)	Preventive Measures (how to block or minimize the risk)	Graduate Risk (after adoption of preventive measures)		
Receiving equipment required for operation.	Intervention of equipment without proper planning	Improper maneuvers in the operation. Shutdown of the facility.	Accompany maneuvers release. Check if what is released corresponds to the configuration requested.	II	A	Negligible
Mounting of skyladder.	Inadequate fixation of the modules of the ladder.	Falling of the electrician. Breaking of the stairs. Damage to the installation.	Assemble according to specific standard. Install ribbon tie between modules. Action of supervision.	II	B	Moderate

Energization of skyladder.	Discharge through the insulating material of the ladder.	Injuries to the linemen. Shutdown bar 69 kV	Monitor the leakage current micro-ammeter; the measured value must be less than 20µA. Perform cleaning with cloth; clean and dry surface insulators.	III	A	Moderate
Working with electrical potential in the skyladder	Electrical discharge to the electrician	Injuries to the linemen. Shutdown bar 69 kV	Obey the safety distances to 69 kV; continuously measure the leakage current in skyladder (maximum 20µA). Action of supervision.	III	A	Moderate
	Electromagnetic induction in the electrician.	Physical discomfort	Perform testing on clothing as conductive material. Electrician must wear clothes according to specific standards.	I	B	Negligible
Handling of materials and tools in heights	Falling of material / tooling.	Injuries to persons on the ground. Damage to equipment / installation	Tie tools. Use bags compatible with the tools. Do not stay under suspended parts. Action of supervision.	II	B	Moderate
Displacement and fixation of jumps energized by the electrical potential	Approaching jump energized or grounded parts with neighboring phase	Electrical burns. Shutdown bar 69 kV	Attention of the electrician. Action of supervision	III	A	Moderate

2.2.2 Operation activity

In the operation tasks of the electric power system, the systems are always located in substations and can be viewed as being composed of two parts:

- Substation courtyard: where equipment is located at high voltages, relays, huts, etc.
- Substation building installations: composed of rooms for offices, rooms for telecommunication equipment, battery rooms, pantries, bathrooms, and rooms for the control center, where operators of the system are stationed 24 hours a day in shifts of six hours.

In general, the operator has a routine that involves receiving information gathered from the previous turn in an application, verifying the functionality of other applications and interventions planned for the zone, observing system conditions on the electrical transmission lines and equipment, switching the equipment and transmission lines regulation and maintenance release, and most importantly, performing tasks aimed at restoring the supply of electricity.

Given the routine of the substation operator, it is possible to make a map showing the risks of occupational accidents to which the operator is exposed in relation to possible causes according to the human-task-environment model proposed, as shown in Table 2 (IIDA et al., 2005).

Table 2: Relationship between the layout/activity and the risks and causes of accidents

LOCAL / ACTIVITY	RISKS	POSSIBLE CAUSES		
		HUMAN FACTOR	ENVIRONMENT	TASK
Thoroughfare **Home - Work. Work - Home.**	**Collision** **Running over** **Ergonomics**	Stress Fatigue Rushing No use of PPE	Bad maintenance of roads Bad maintenance of vehicle Inadequate lighting	**Work overload**
Control Room **Monitoring** **Administrative services**	**Ergonomics** **Electric shock** **Fall**	Stress Fatigue Lack of concentration Insecure posture	Inappropriate furniture Slippery/uneven floor Noise	**Work overload** **Work Schedule** **Cognitive overload**
Motor Generator Room **Checking and testing**	**Ergonomics** **Electric shock** **Fall** **Burn**	Lack of attention Self-reliance No use of PPE	Poorly designed equipment Space and movement problem Slippery/uneven floor Exposure to hot liquids	**Work overload** **Work Schedule**
Auxiliary Services Room **Checking equipment**	**Ergonomics** **Electric shock** **Fall**	Stress Fatigue Lack of concentration	Poorly designed equipment Space and movement problem Slippery/uneven floor	**Work overload** **Work Schedule**
Courtyard **Inspection equipment**	**Ergonomics** **Electric shock** **Fall** **Insect attack** **Burn**	Self-reliance Stress Fatigue No use of PPE Lack of attention Insecure posture	Defective tools Uneven floor Exposure to electricity Exposure to hot liquids	**Work overload** **Work Schedule**

Source: own elaboration

3. METHODS AND MODELS

The method used in this study consisted primarily of literature and exploratory research. Exploratory data were collected from internal documents of the electricity sector. These accidents data were collected from five years of operation of an electric company in Northeast Brazil. These data were acquired through accidents internal reporting which resulted in a total of 546 events.

Individual variables such as worker age, and temporal variables, such as day of week, month, and hour of occurrence were analyzed. Also analyzed were the variables such as geographic area, accident locale, accident category such typical or work way (accidents in direction which occur between home and the workplace); with and without absenteeism, disability type, and days absent due to accident. Analysis was carried out using a statistical method with the software called R (R- PROJECT, 2013).

4. DATA ANALYSIS OF ACCIDENTS INDICATORS

Figures 2 to 12 show the data rates of accidents due to the variables: accident data depending on accident category such typical or work way, with and without absenteeism; accident data depending on the type of disability; and number of days lost due to accidents.

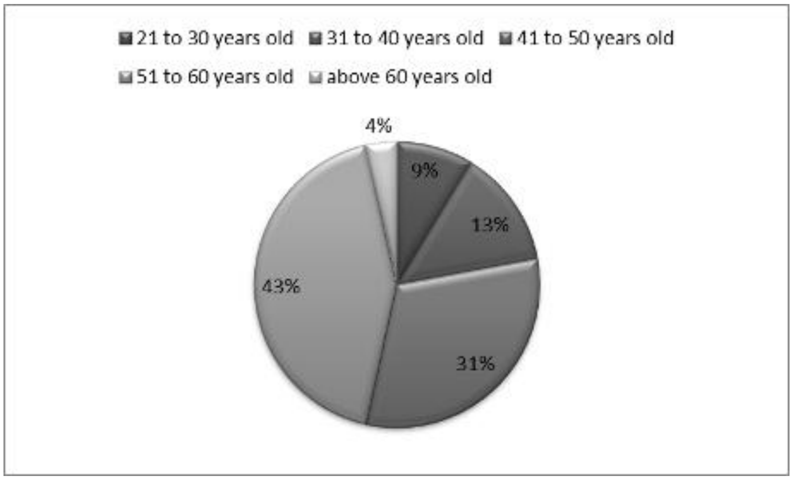

Figure 2 - Index of accidents according worker age. Source: Field Data

As shown in Figure 2, the highest incidence of accidents (43%) occurred among worker 51 to 60 years of age, following by workers 41 to 50 years of age (31%).

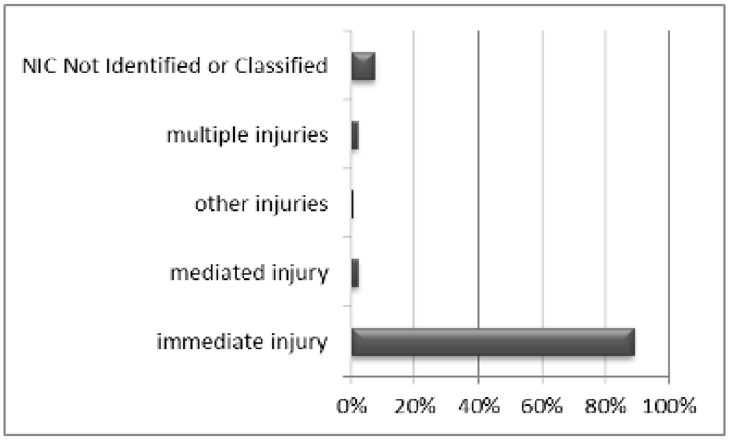

Figure 3 - Index of Lesions of the accident. Source: Field Data

As shown in Figure 3 Most important lesions were classified as immediate (89%) which includes the crushing and bruising (35%), the strains and sprains (16%), superficial injuries (14%).

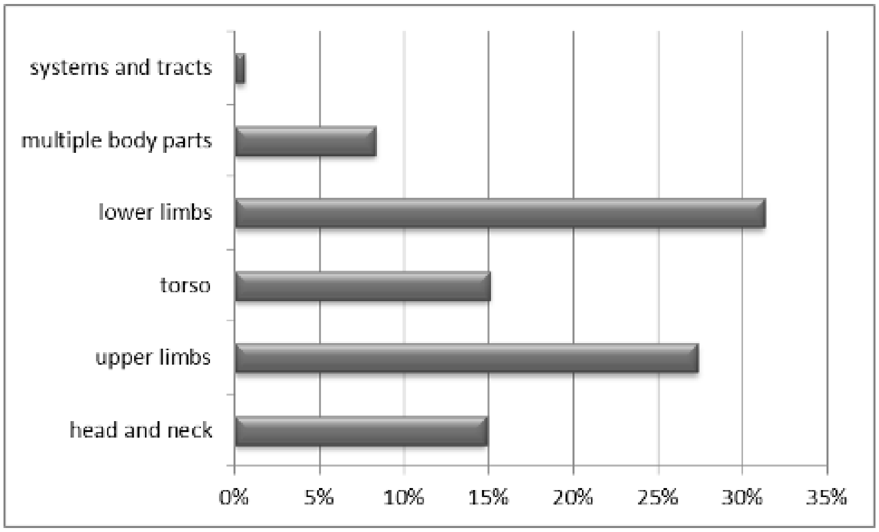

Figure 4 - Index of regarding of the lesions

As shown in Figure 4 Regarding the location of the lesions, most occurred in members: lower limbs (31%) and upper limbs (27 %).

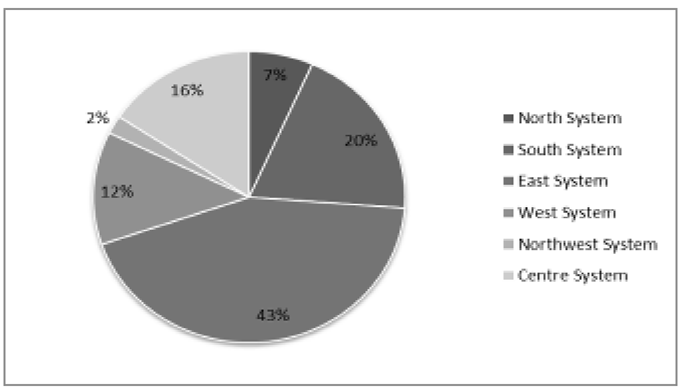

Figure 5 - Geographic locale of accident occurrence Source: Field Data

Figure 5 shows that the highest incidence of accidents occurred in the East System (43%) followed by the South (20%). It appears, however, that this variable requires further examination to explain this large variation, since this information does not match the same relative magnitude of the system, considering all the transmission lines, the substations, and the installation capacity of these systems.

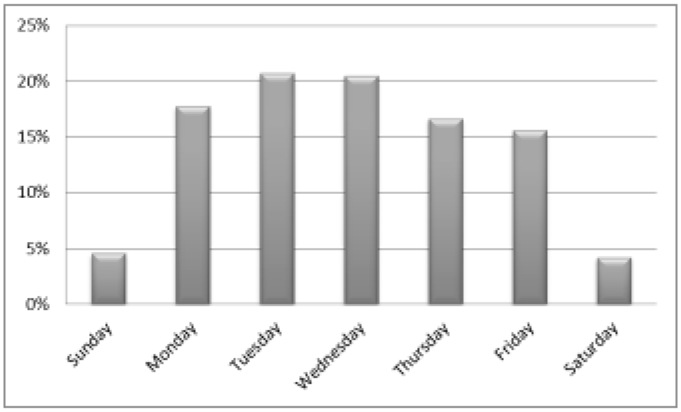

Figure 6 - Index of accidents according to the week day of occurrence. Source: Field Data

According to Figure 6, the highest accident rate occurs on Tuesdays and Wednesdays (40%), followed by Mondays. On Saturdays and Sundays this figure falls to 10%, which is expected due to reduced work activities. It appears, however, that this variable needs to be explored more deeply to determine the variation of reduction on Thursdays and Fridays.

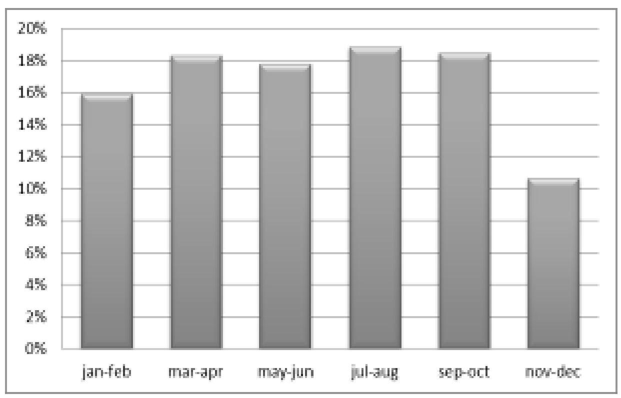

Figure 7 - Index of accidents according to the month of occurrence. Source: Field Data

An analysis of occurrences in two-month periods between January and October indicates a balance in the range of 16% to 19%, as shown in Figure 7. In the two-month period of November and December, there is a reduction to 10%. This variable needs to be investigated more deeply to determine this variation reduction in the months of November and December and to find out why there is no drop in January and February, during which the number of employees is very low due to summer vacations.

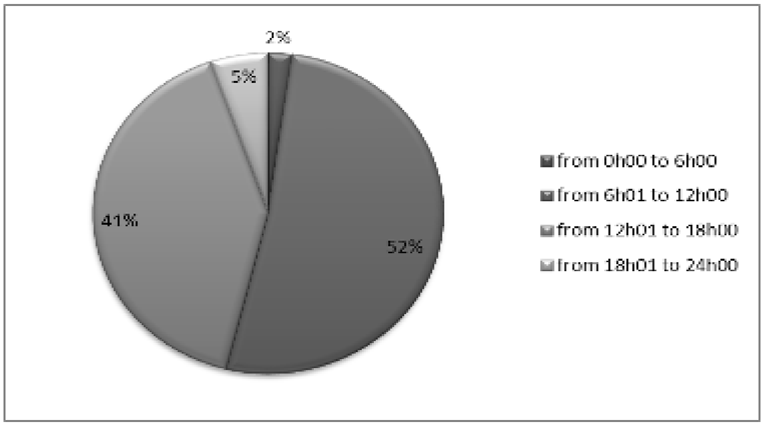

Figure 8 - Index of accidents according to the day hour of occurrence. Source: Field Data

In general, the highest rate of accidents (52%) occurred in the morning, then in the afternoon (41%), as shown in Figure 8. It can be argued, however, that these rates are almost equal to each other.

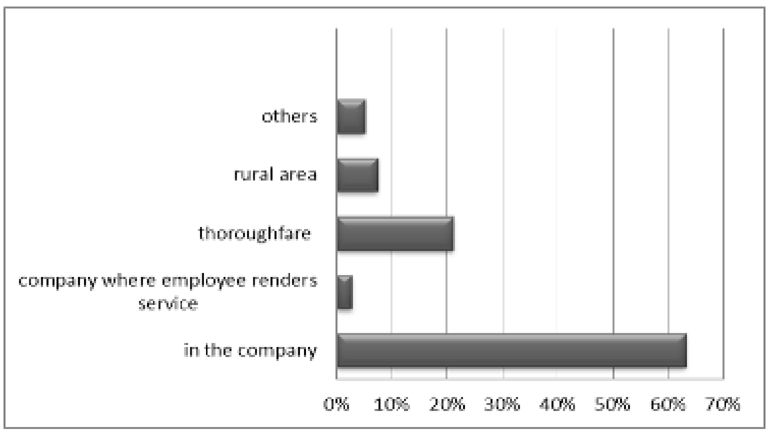

Figure 9 - Index of accidents according to the accident locale. Source: Field Data

According to the data in Figure 9, the majority of accidents seem to occur in own installations.

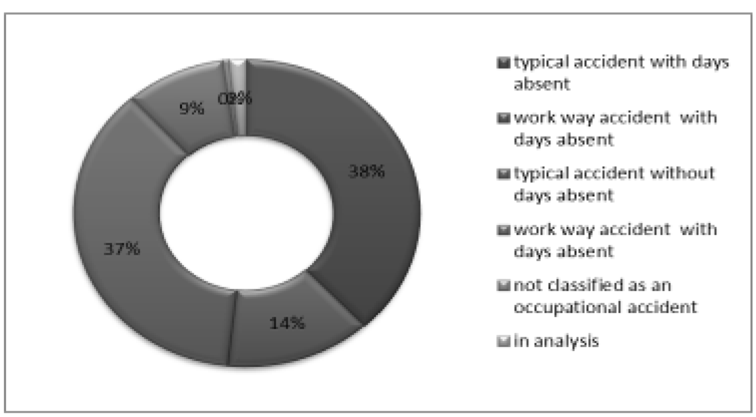

Figure 10 - Accident data depending on their category (typical or path) with and without days absent. Source: Field Data

Where category of accident is concerned, typical accidents with days absent the highest incidence (38%), followed by typical accidents without days absent (37%). Figure 11 shows temporary disability to be prevalent at 94%, with permanent disability at 6%.

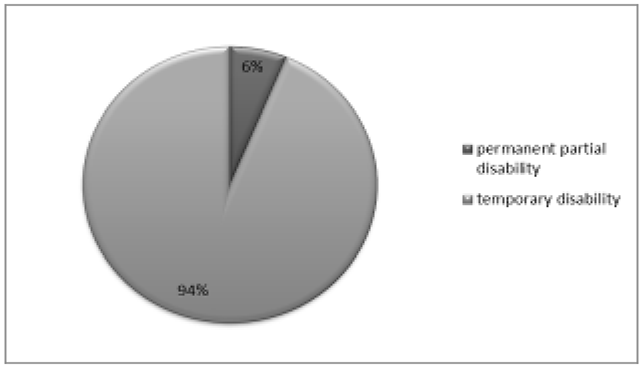

Figure 11 - Accident data depending on the type of disability type. Source: Field Data

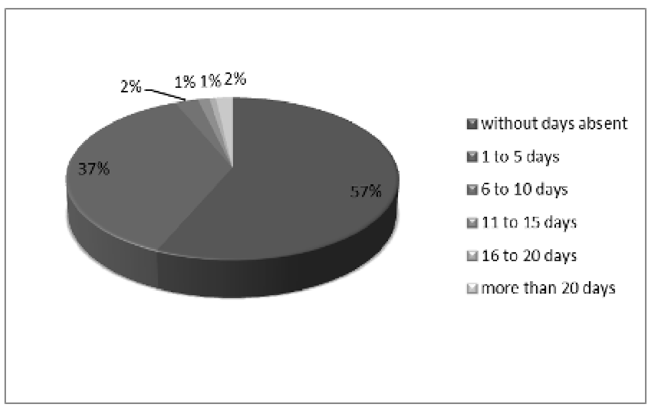

Figure 12 - Number of days absent (DA) due to accident. Source: Field Data

As seen in Figure 12, accidents mostly do not involve absent days (57%); a large number (37%), however, result in 1 to 5 days absent (DA).

5. STATISTICAL ANALYSIS

The dependentvariable selected for this work was number of days absent (DA) due to a work accident. The independent variables were working time in the company, hereinafter called "working time" (WT), and age (WA). The negative binomial regression model is suitable for count data when overdispersion is observed. This phenomenon occurs when the dependent variable is the Poisson' distribution but the variance is greater than the median.

Poisson regression models have many desirable properties to describe the relationship between count data. According to Miaou et al. (1993), however, the data presenting significant overdispersion using the Poisson regression models may overestimate or underestimate the probability of occurrence of the dependent variable. Thus more general probability distributions should be used as the negative binomial.

The model used by Abdel-aty et al. (2000) was a negative binomial regression to model the frequency of traffic accidents. The models they obtained showed that younger and older drivers suffer more accidents than middle-aged drivers do when the volume of traffic is more intense and the shoulders and raised plants have smaller widths. They concluded that the negative binomial regression model is superior to the Poisson model, and added to the literature the possibility of including the effects of age of the drivers when modeling traffic accidents.

Based on the aforementioned studies and considering a preliminary descriptive analysis of the data collected, we adopted the negative binomial regression model to establish the relationship between the variables of days absent (DA), worker age (WA), and working time (WT).

5.1 Results and discussion

Initially the observations were separated into classes with respect to three variables, DA, WA, and WT, to better visualize their behavior. Thus, Figure 13 shows the frequency of days absent according to different classes.

Figure 13 show that the class of 1 to 22 days absent (DA) has the highest frequency, with 92 cases of the 114 total cases.

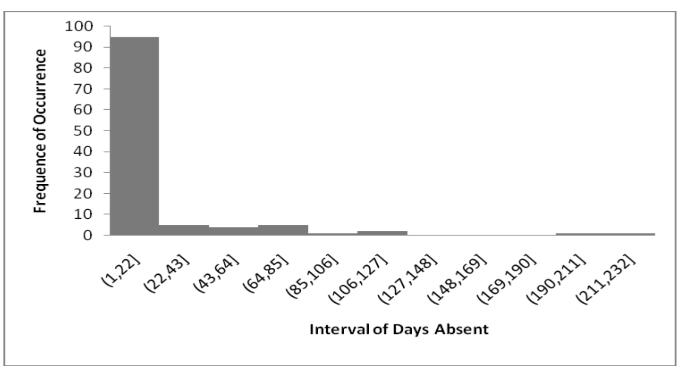

Figure 13 – Frequency occurrence graphs in function of the interval of days absent (DA).Source: Own elaboration

Comparing the results with the data obtained from the research of Blanch *et al.* (2009), which guided the analysis, there appears to be a relationship between the variable WA and others. A fact to be considered is that the age of the sample collected in this work can be said to be higher in comparison with the study of Blanch et al., (2009).

In their results, he confirmed the hypothesis that releasing the scatter plot between days absent and worker age results in a "U", indicating that the most serious accidents occur with workers 20 to 30 years of age and those 55 to 60 years of age, as can be seen in Figure 14. In this reference LWDI means the days absent (DA) due to an accident at work and age is the worker age (WA).

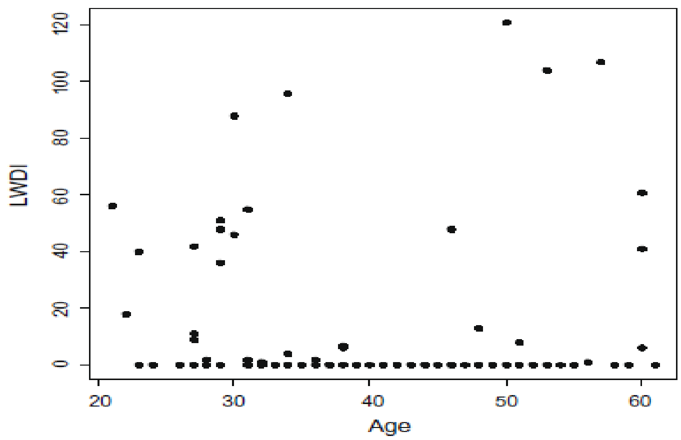

Figure 14 – Dispersion graphs among variables LWDI and worker age. Source: Blanch et al.. (2009)

The explanations of non-respect of the variable WA with the dependent variable DA in these models may reside in the fact that the greatest number of days lost due to accidents at work occurred among individuals between 40 to 55 years of age, as can be seen in Figure 15. In addition, accidents involving individuals from other age groups stood at around 30 days absent, even as Figure 15 shows homogeneity, which may have led to no significant variation in the influence of worker age (WA) and days absent (DA).

Figure 15 – Graphs of dispersion between the variables worker age (WA) and days absent (DA). Source: Own Data

5.1.2 Statistical Model

In the Table 3 is shown the models: m6_log with SQR_{m6_log} = 127.1704, SQR_{m2_log} = 127.7363 and SQR_{m5} = 129.2426.

Table 3 – StatisticalModelsConsidered

Model	SQR	Equation
m6_log	127.1704	$DA = e^{(2,4874+0,1381*TT-0,0022*ID*TT)}$
m2_log	127.7363	$DA = e^{(2,5922+0,02092*WT)}$
m5	129.2426	$DA = (0,09898 * WA)^2$

In the model m6_log assumes that the lost days can be predicted by an exponential function, given the variable WT and the interaction between WA and WT, where, unlike the other models surveyed in this study, variable WA has an impact on variable DA, when combined with WT.

Moreover, keeping the variable WT constant is expected to reduce the lost days with decreasing age of the person. The hypothesis is that younger employees would have a greater ability to recover after an accident, thus requiring less time to return to work.

In the model m2_log makes a prediction of variable DA by an exponential function that considers only variable WT. Thus, it can be said that increasing the working time of the company employee suggests that the number of days lost follows an exponential increase. A hypothesis to explain this model is the possibility that employees, in exercising the same function over time, become careless about safety standards, believing they are already wellaccustomed to the activities performed. This may result in more accidents and in more lost days. In the model m5 the variable WA is significant when viewed in isolation. An increase in the amount of days lost due to accident is related to an increase in the age of the worker.

6. GENERAL CONSIDERATIONS AND CONCLUSIONS

- There was a large reduction in accident rates of the last thirty years. The reduction of these accidents occurred due to the efforts of electric company's management and monitoring work of the professionals working in the area.
- It is noteworthy that during this period there was a restructuring of the electricity sector in Brazil with the fusion and creation of new businesses and new regulatory agentswich penalization, monitoring work and sanctions and penalties.
- An analysis of occurrences in a month shows a balance in the range of 16% to 19% in the interval between January and October. In the months of November and December there was a reduction to 10%. However, it appears that this variable needs to be examined more deeply to determine why this reduction occurs.
- In terms of worker age, the highest incidence of accidents (74%) occurs with more experienced workers in the company, specifically in those workers 41 to 60 years of age.
- Using a negative binomial regressive statistical model it was determined the influence of the independent variables of worker age (WA) and working time (WT) in the behavior of the dependent variable of days absent (DA). This was concluded based on three statistical models with validity confirmed for the data collected, where different considerations were established.
- Young workers would be more able to recover after an accident, requiring less time to return to work.
- Workers who exercise the same function over time become careless about safety standards, believing they are already well accustomed to the activities performed, which may cause more accidents, resulting in more days absent.
- An increase in the amount of days lost due to accident is related to an increase in the age of the worker.

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UM ESTUDO DE CASO DE ANÁLISE DE SEGURANÇA DO TRABALHO EM SISTEMAS DE ENERGIA ELÉTRICA DO BRASIL

RESUMO: Os riscos associados ao trabalho no setor de energia são: riscos elétricos, quedas e riscos ocupacionais. Descrever os riscos no setor elétrico, particularmente através de dados de uma empresa de energia elétrica no Nordeste do Brasil. Esses dados foram adquiridos através de relatórios internos de acidentes que resultaram em um total de 546 eventos. Foram analisadas variáveis como idade do trabalhador, dia da semana, mês e hora de ocorrência. Em termos de idade do trabalhador, a maior incidência de acidentes (74%) ocorre com trabalhadores mais experientes na empresa, especificamente trabalhadores de 41 a 60 anos de idade. Um aumento na quantidade de dias perdidos por acidente está relacionado a um aumento na idade do trabalhador. Utilizando um modelo estatístico, determinou-se a influência da idade do trabalhador (WA) e do tempo de trabalho (WT) no comportamento da variável dependente dos dias ausentes (DA).

Palavras-chave: Análise de risco do trabalho; Segurança elétrica; Modelo estatístico de dados de segurança.

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