UNIVERSIDADE FEDERAL DE PERNAMBUCO
PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA DE PRODUÇÃO

NEW TAXONOMY AND MODEL OF ERROR SEQUENCE PROCESS FOR HUMAN ERROR ASSESSEMENT IN HYDROELECTRIC POWER SYSTEMS

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RÔMULO FERNANDO TEIXEIRA VILELA

"NEW TAXONOMY AND MODEL OF ERROR SEQUENCE PROCESS FOR HUMAN ERROR ASSESSEMENT IN HYDROELECTRIC POWER SYSTEMS"

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DEDICATION

To my father Jorge Vilela and my mother Gerusa Vilela (*in memorian*);
To my family Carol, Rodrigo, Rômulo Fernando and Polyana;
To my advisor and fellows from CEERMA;
To my co-advisors Marcelo Martins and Paulo Frutuoso;
To all who helped me in CHESF.

ABSTRACT

With advances in hardware reliability engineering in the last 30 years, we have seen equipment and complex systems with very low levels of failure. Complex systems in the nuclear industry, aerospatiale sector, chemical industries, electrical industries and others now have equipment and systems with levels of reliability that has adequately served the society. However, the operation and maintenance of these systems do not rely solely on intrinsec performance of the corresponding equipment, but they also depend on human action. Major accidents in the recent past such Chernobyl, Bhopal, the Challenger shuttle and major recent power blackouts in Brazil, highlighted the need to reduce human error in complex systems. The human reliability assessment emerges as a support to the analisys of the operation and maintenance of these type of systems. Since the late 80^{th} some advances have emerged in the study of human reliability. Techniques such as THERP, ATHEANA, CREAM and IDAC, have been consolidated over time for the study, measure and prediction of human error. However performance shaped factors used in almost all the aforementioned techniques have proven difficult to be estimated from a practical standpoint. In addition, the specifics of the Hydroelectric Power Industry defined in the Grid Procedures of the National System Operator (Operador Nacional so Sistema, ONS) and the regulatory instruments of ANEEL (Agencia Nacional de Energia Eletrica) Regulatory Agency have led to the necessity of a taxonomy that can adapt for this important strategic sector. In this thesis, it is proposed a taxonomy and model of error sequence process for assessment of human error specifically designed to meet the context of operation and maintenance of Hydroelectric Power System. To illustrate the new taxonomy it was collected and analyzed data from about ten years of human error records related to the generation and transmission of Hydroelectric Power Company in Brazil. It was collected 605 reports by human error shutdown from 1998 to 2009. A BBN-Base methodology for the quantification of human error is also discusses. The taxonomy, model for error sequence process as well as the BBN-Based model are illustrated via an example of application in the context of the Brazilian Hydroelectric Power Industry.

***Keywords**: Human error; Human Reliability Analysis (HRA); taxonomy; Electric Power System; Bayesian networks; Performance; Shaped Factors (PSFs), expert opinion.*

RESUMO

Com os avanços em hardware, a engenharia de confiabilidade nos últimos 30 anos, tem nos mostrado equipamentos e sistemas complexos com níveis de falha muito baixos. Sistemas complexos na indústria nuclear, aeroespacial, química, elétrica entre outras possuem hoje em dia equipamentos e sistemas com níveis de confiabilidade que tem atendido adequadamente a sociedade. Entretanto, a operação e manutenção destes sistemas não dependem exclusivamente do desempenho intrínseco dos correspondentes equipamentos, dependem também da ação humana. Grandes acidentes no passado recente como Chernobyl, Bhopal, da nave Challenger e os grandes apagões no Brasil, colocaram em evidência a necessidade de redução do erro humano em sistemas complexos. A análise da confiabilidade humana surge assim como um apoio para a análise destes sistemas de operação e manutenção. Desde a década de 80 alguns avanços foram surgindo no estudo da confiabilidade humana. Técnicas como THERP, ATHEANA, CREAM e IDAC, se consolidaram ao longo do tempo como boas aplicações práticas para estudar, medir e prever o erro humano. Porém os fatores de desempenho utilizados em quase todas as técnicas supracitadas, tem se mostrado difíceis de serem estimados de um ponto de vista particular. Além disso, as particularidades do setor Hidroelétrico de Potência, definidas nos Procedimentos de Rede do Operador Nacional do Sistema (ONS) e nos instrumentos normativos da Agencia Reguladora ANEEL têm levado a necessidade de uma taxonomia que possa se adaptar a este importante e estratégico setor. Nesta tese, é proposta uma taxonomia e um modelo da sequência do processo de erro, para avaliação deste erro humano especificamente concebido para atender ao contexto de operação e manutencão do Sistema Hidroelétrico de Potência. Para ilustrar a nova taxonomia, foram coletados e analisados dados de cerca de dez anos de registro de erro humano de uma empresa de geração e transmissão de energia elétrica brasileira. Foram coletados 605 relatórios de desligamento por erro humano desde 1998 até 2009. Uma metodologia BBN-Base para a quantificação do erro humano é também discutida. A taxonomia e o modelo da sequência do processo de erro humano tanto quanto o modelo BBN-Based são ilustrados via um exemplo de uma aplicação no contexto de uma indústria Brasileira Hidroelétrica de Potência.

***Palavras-chave**: Erro humano; Análise de Confiabilidade Humana (HRA); Taxonomia; Sistema Elétrico de Potência; Redes Bayesianas; Fatores de desempenho (PSFs); Opinião de especialistas.*

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LIST OF ACRONYMS

ANEEL – Agência Nacional de Energia Elétrica

ATHEANA – A Thecnique for Human Error Analysis

BN – Bayesian Network

CREAM – Cognitive Reliability and Error Analysis Method

CTP – Conditional Probabilities Table

GEMS – Generic Error Modeling System

HE – Human Error

HEP – Human Error Probability

HET – Human Error Taxonomy

HFE – Human Failure Event

HRA -Human Reliability Analysis

HTA – Hierarchical Task Analysis

IDAC - Information Perception, Diagnosis and Decision Making, and Action Taking in Crew Perspective

MW – Mega Watt

ONS – Operador Nacional do Sistema

PRA – Probabilistic Risk Analysis

PSA – Probabilistic Safety Analysis

PSF – Performance Shaped Factors

RDFH – Human Error Shutdown Report (Relatório de desligamento por falha humana)

SRK – Skill-Rule-Knowledge

THERP – Technique for Human Error Rate Prediction

SUMMARY

1. INTRODUCTION

1.1 Overview

As long as electricity is available, no one thinks much about it. The importance is realized when the power goes out. Whether it is during the day or at night, electricity keeps people lives in order. It affects their business, schedule and even their entertainment. Electricity runs everything in people's everyday life. Gas stations can not pump gas without it. Businesses have to close because their cash registers would not work without it. Restaurants can not cook food without it. Everything nowadays depends on having power to keep them running. The main effort is thus against its outage. A power outage (also known as a power cut, power failure, power loss, or blackout) is a short- or long-term loss of the electric power to an area. There are many causes of power failures in an electricity network. Examples of these causes include faults at power stations, damage to power lines, substations or other parts of the electricity system, a short circuit, or the overloading of electricity mains. The major causes of power system downtime include utility outages, human error, externally and internally generated disturbances, and maintenance of power system components and failure of power system components. Disruptions in incoming utility power are unavoidable, whether caused by lightning strikes, construction projects or problems with power equipments.

A widespread blackout can affect large areas. This demonstrates just how quickly a small problem in one area can ripple across the grid to create a widespread outage. To avoid power outages or blackouts, for decades the focus has been on increasing the reliability of electric equipments and increase the flexibility and interconnection of transmission systems. As a result, the reliability of hydroelectric power system has improved. With more reliable equipments and safer work process the focus has shifted to human error. In fact, human error has become one of the main factors for systems reliability measurement, not only on power electric systems but also in areas like Nuclear Power Plants, Aviation, Shipping Industry, Communication Networks, Chemical Industry and the like. According to Rasmussen (1999), the analyses of industrial accidents have often concluded that human error is a determining factor in 70-80% of the cases.

Based on Rasmussen (2003), in the 1970s and 1980s there was great interest among applied psychologists and systems reliability engineers in analyzing accidents and "near miss" incidents in large scale systems where public safety was a primary concern. Efforts to define and develop taxonomies of human error were then in curse. Works from authors such Rasmussen (1999), Reason (2005) and Hollnagel (1998), have provided the basis for the structured and systematic formalism for developing and implementing human error taxonomies. The main reasoning is that the development of human error taxonomies emerge as the first step to understand the human error process and then propose alternatives to mitigate and/or to avoid these undesirable events.

Since the late 80th great advances have emerged in the study of human reliability. Techniques such as THERP, ATHEANA, CREAM and IDAC, have been consolidated over time for the study, measure and prediction of human error. However performance shaping factors used in almost all the aforementioned techniques have proven difficult to be estimated. In addition, the specifics of the Electric Power Sector defined in the Grid Procedures of the National System Operator (Operador Nacional so Sistema, ONS) and the regulatory instruments of ANEEL (Agencia Nacional de Energia Eletrica) Regulatory Agency, have led to the necessity of a taxonomy that can adjust for this important strategic sector.

1.2 Motivations and justifications

It is observed that 1st generation techniques for Human Reliability Analysis have some shortcomings. Among them, unrealistic assumptions of independence and simple binary representation of events. This is because 1st generation techniques try to adapt tools from Equipment Reliability Engineering such as event tree and fault tree analysis to quantification probability of human errors. These techniques fail on modeling human actions. Human behavior is much more complex than behavior of equipments and analytical systems.

In 1982, Rasmussen presented the concepts of Performance Shaped Factors (PSFs) as an attempt to introduce psychological questions on modeling human behavior. The classification Skill-Rule-Knowledge (SRK) for human error proposed by Rasmussen in this same paper represented an important advance. The concept of Failure Mode (FM) firstly presented by Rasmussen in 1982 and after developed by Reason in 1990 consolidated the human error assessment not as an analytical system but as a system with human beings. Among these techniques, in 1998, Hollnagel presented the Cognitive Reliability and Error Analysis Method (CREAM) as an attempt to quantify more explicitly the influence of psychological factors on workers performance. Hollnagel proposed a polychotomous classification as a generalization of the event tree. However, the assumption of independence among events and not able to deal dynamic contexts remained a problem. A methodology developed by Chang & Mosleh

(1999) brought a major evolution for HRA, as they incorporated many advances in relevant areas of cognitive psychology, behavioral sciences, neuroscience, and human factors, among others. This progress made it possible to consider the independence among most of the PSFs. However, the independent relationship between external factors and psychology factors is not considered which is a shortcoming of this method. Other disadvantages were also observed such as not being possible to quantify the influence between two workers and not to consider the influence between events. These problems arise because of the difficulty in modeling human actions through event trees. It is clear that the major challenge for HRA have been to model the existing causality in human actions. Some of the 3rd generation uses Bayesian network to solve this problem. Menezes and Droguett (2005) presented a methodology for using Bayesian network for evaluating human reliability in activities of replacement of insulator chain in transmission lines. Bayesian networks provide greater flexibility as they allow a more realistic representation of the dynamic nature of the interface between system and man-man events in normal or abnormal process, and also allows for representation the relationship of dependency between events and between the performance factors despite the use of Bayesian network, the use of PSFs have been a problem to get data about human behavior even. The elicitation about the influence of PSFs on human error is difficult [Souza, Firmino & Droguett (2010)]. Thus, this work proposes a taxonomy and model for the error sequence process in the context of human error in hydroelectric ower ystems. It also makes use of BBN to develop a quantification model for Human Error Probabilits.

1.3 Objectives

1.3.1 General Objective

A new taxonomy and model of error sequence process to assess the human error in Hydroelectric Power Systems.

1.3.2 Specific Objectives

- Develop a new taxonomy for human error assessment based on the hibridism of Rasmussen(1982)/Reason(1990) taxonomy and the elementary behavior of Berlinner(1964);
- Develop a model that describes the sequence of the error process when human error occurs during interventions (operation/maintenance) in hydroelectric power systems;

- Apply the proposed taxonomy and model to a real case in the context of a hydroelectric company in northeastern Brazil;
- Develop a BBN-based model for quantification human error based on the proposed taxonomy and model of sequence error process.

1.3.3 Thesis lay-out

This thesis is organized as follows: Chapter 2 presents an overview about the Brazilian power electric system, the importance of electricity nowadays and problems when blackouts are caused by operational discontinuity of the power electric system. Chapter 3 presents a literature review about human error involving human reliability, human error and human error taxonomy. Chapter 4 presents a new taxonomy to classify the human error and a new model to describe the sequence of human error on power electric systems. In sequence, Chapter 5, is presented the importance of analysis of human error, the form of registration these human errors and a descriptive statistics of human between 1998 and 2009 in the company object of this study. Chapter 6 develops applications about this new model with the new taxonomy. Examples contribute to validate the new taxonomy and the new model is here presented. First, a qualitative application is presented to investigate human error occurred and proposal adjusts on prevention program. In sequence, a Bayesian network application is developed to quantification the human error probability during tasks of operation/maintenance of power electric systems, and a Toy Model is presented to validate the model. The last chapter (Chapter 7) presents conclusions and opportunity to develop new approach about the human error for power hydroelectric system.

2. HYDROELECTRIC POWER SYSTEM

This chapter presents an overview about the Brazilian hydroelectric power system, its history; importance to development of the country; capability and current resources. Also, shows the failure of the electric system and its consequences when a blackout occurs.

According to Eletrobrás (source: www.eletrobras.com) electricity was introduced in Brazil in the 19th century through the concession of privileges for the exploration of public illumination given by Emperor D. Pedro II to Thomas Edison. In 1930, the installed power in Brazil reached 350 MW in power plants that are now considered of low power, owned by industries and municipal administrations, most of them hydropower plants. In 1939, in Varga's Administration, the Waters and Energy National Council was created, a regulatory and inspection organ, later replaced by the Waters and Electric Energy National Department – DNAEE – under the authority of the Ministry of Mines and Energy. The first half of the 20th century represents the phase that confirms electricity generation as an activity of economic and strategic importance for the country. From the Second World War on, the Hydroelectric power system has a large thrust with the construction of the first large power plant, namely Paulo Afonso I, with a power of 180 MW, followed by the Furnas, Três Marias and other power plants with large reservoirs. In June 11, 1962 the Eletrobrás (Brazilian Electric Power Company) was established, in a solemn session of the Conselho Nacional de Aguas e Energia Eletrica (Cnaee) at Laranjeiras Palace in Rio de Janeiro. Eletrobrás is a mixed economy and open capital company controlled by the Brazilian government, which operates in the areas of generation, transmission and distribution of electricity. With shares traded on stock exchanges in Sao Paulo, New York, USA and Madrid, Spain, and focus on profitability, competitiveness, sustainability and integration, the company manages 12 subsidiaries - Eletrobrás Furnas, Eletrobrás Chesf, Eletrobrás Eletronorte, Eletrobrás Eletrosul, Eletrobrás Eletronuclear, Eletrobrás CGTEE, Eletrobrás Amazon Energy, Eletrobrás Boa Vista Energia, Eletrobrás Ceal, Eletrobrás Cepisa, Eletrobrás Ceron and Eletrobrás Eletroacre. Also, Eletrobrás Eletropar, a shareholdings company, an Electric Power Systems Research Center (Cepel) and still owns 50% of Itaipu Binacional, one company shared with the government of Paraguay. Together these companies form Eletrobrás. Eletrobrás generating capacity, including half of the Itaipu Binacional, is 39,413 MW, which corresponds to about 38% of total generation in the country. This energy is produced by 30 hydroelectric plants, 15 thermoelectric plants and two thermonuclear plants. Eletrobrás has 59,856 km of transmission lines, representing about 56% of the total lines that cut through Brazil, as well as 247 substations. At the end of the sixties, the Interconnected Operation Coordination Group (GCOI) was created, giving birth to the Interconnected National System. During its 100 years of existence, the Brazilian electric system has predominantly been a hydraulic one. Today, the power electric matrix is 85% of hydraulic power plants and 15% thermo power plants The Brazilian electric power system nowadays has a generation capability of 92TW. In 2005 were generated on the average of 46TW of power with a maximum consumption of 60TW. This energy corresponds to 55% of production on South America and is equivalent to that of countries like Italy and the UK. Besides, it operates and maintains this system in compliance with the performance and quality standards required by the National Agency of Electrical Power (ANEEL). The Brazilian electric power system has been actively taking part in the transmission and generation expansion through concessions in auctions promoted by ANEEL, solely or by means of consortiums, as well as through authorizations to reinforce the current system. The Brazilian power electric system has developed an important role in the development of the country. Today's society is very demanding with the maintenance of continuity of supply of electric power. A power outage, power cut, power failure, power loss, or blackout, is nowadays a very serious undesirable event with bad consequences. Power outages are categorized into three different phenomena, relating to the duration and effect of the outage:

* A transient fault is a momentary (a few seconds) loss of power typically caused by a temporary fault on a power line. Power is automatically restored once the fault is cleared.

* A "brownout" or "sag" is a drop in voltage in an electrical power supply. The term brownout comes from the dimming experienced by lighting when voltage sags.

* A "blackout" refers to the total loss of power to an area and is the most severe form of power outage that can occur. Blackouts which result from or result in power stations tripping are particularly difficult to recover from quickly. Outages may last from a few minutes to a few weeks depending on the nature of the blackout and the configuration of the electrical network. Power failures are particularly critical at sites where the environment and public safety are at risk. Institutions such as hospitals, sanitary sewage treatment plants, mines, etc., will usually have backup power sources, such as emergency power system generators, which will automatically start up when electrical power is lost. Other critical systems, such as telecommunications, are also required to have emergency power. Telephone exchange rooms usually have arrays of lead-acid batteries for backup and also a socket for connecting a

generator during extended of outage periods. Different types of electrical apparatus will react in different ways to sag. Some devices will be severely affected, while others may not be affected at all.

* Commutated electric motors, such as electric motors, whose mechanical power output also varies with the square of the applied voltage, will run at reduced speed and reduced torque. Depending on the motor design, no harm may occur. However, under load, the motor will draw more current due to the reduced back-EMF developed at the lower armature speed. Unless the motor has ample cooling capacity, it may eventually overheat and burn out.

* An AC induction motor will draw more current to compensate for the decreased voltage, which may lead to overheating and burnout.

* An unregulated direct current linear power supply (consisting of a transformer, rectifier and output filtering) will produce a lower output voltage for electronic circuits, with more ripple (electrical) ripple, resulting in slower oscillation and frequency rates. On a television monitor, this can be seen as the screen image shrinking in size and becoming dim and fuzzy. The device will also attempt to draw more current in compensation, potentially resulting in overheating.

* A switching power supply may be affected, depending on the design. If the input voltage is too low, it is possible for a switching power supply to malfunction and self-destruct.

*Brownouts can cause unexpected behavior in systems with digital control circuits. Reduced voltages can bring control signals below the threshold at which logic circuits can reliably decide which state is being represented. As the voltage returns to normal levels the logic can find itself latched into an incorrect state; even can not happens states become possible. The seriousness of this effect and whether steps need to be taken by the designer to prevent it depends on the nature of the equipment being controlled; for instance a brownout may cause a motor to begin running backwards.

Under certain conditions, a network component shutting down can cause current fluctuations in neighboring network segments, though this is unlikely, leading to a cascading failure of a larger section of the network. This may range from a building, to a block, to an entire city, to an entire electrical grid. Modern power systems are designed to be resistant to this sort of cascading failure, but it may be unavoidable. Moreover, since there is no short-term economic benefit to preventing rare large-scale failures, some observers have expressed concern that there is a tendency to erode the resilience of the network over time, which is only corrected after a major failure occurs. It has been claimed that reducing the likelihood of small outages only increases the likelihood of larger ones. In that case, the short-term economic benefit of keeping the individual customer satisfied increases the likelihood of large-scale blackouts. Restoring power after a wide-area outage can be difficult, as power stations need to be brought back on-line. Normally, this is done with the help of power from the rest of the grid. In the total absence of grid power, a so-called black start needs to be performed to Bootstrapping (electronics) bootstrap the power grid into operation. The means of doing so will depend greatly on local circumstances and operational policies, but typically electric power transmission utilities will establish localized 'power islands' which are then progressively coupled together. To maintain supply frequencies within tolerable limits during this process, demand must be reconnected at the same pace that generation is restored, requiring close coordination between power stations, transmission and distribution organizations. Cascading failure becomes much more common close to this critical point. The power law relationship is seen in both historical data and model systems. The practice of operating these systems much closer to their maximum capacity leads to magnified effects of random, unavoidable disturbances due to aging, weather, human interaction and so on, while near the critical point these failures have a greater effect on the surrounding components due to individual components carrying a larger load. This results in the larger load from the failing component having to be redistributed in larger quantities across the system, making it more likely for additional components not directly affected by the disturbance to fail, igniting costly and dangerous cascading failures. These initial disturbances causing blackouts are all the more unexpected and unavoidable due to actions of the power suppliers to prevent obvious disturbances (cutting back trees, separating lines in windy areas, replacing aging components etc). The complexity of most power grids often makes the initial cause of a blackout extremely hard to identify. The effects of trying to mitigate cascading failures near the critical point in an economically feasible fashion are often shown not to be beneficial and often even detrimental. On hydroelectric power systems, most human errors do not produce bad outcomes such discontinuity in the supply of electrical energy , because they could had been immediately corrected by the operator that committed this error or the subsystem and/or equipment was delivered to maintenance (out of operation), or because the consequences were only lost of time to make a re-work. On the other hand, some human error on hydroelectric power systems could produce catastrophic outcomes like blackouts. Some blackouts may last for hours and even days. The operational discontinuity of electricity became great loses for the company who provides energy and even more for the society around affected by blackout. Nowadays, human error arises in importance due to the great developed of equipment and material reliability on last decades. This enormous development has reduced the relative failure rate from equipment and material on global failure in complex industrial systems. Growing in importance in the 20th century, human element researches have been received many resources. "Human error has been cited as the dominant cause of many of the major industrial disasters in recent history. Perhaps the main reason for the visibility of human cause of failure of complex technological systems is the enormous progress made in the 20th century in improving the levels of reliability and safety of such systems leaving the human element behind", according to Chang & Mosleh (1999).

3. HUMAN ERROR OVERVIEW

This chapter presents initial concept of human error, a literature review on human reliability and taxonomy of human error proposed by Rasmussen and Reason

“An erroneous action can be defined as an action which fails to produce the expected result and/or which produces an unwanted consequence”, according to Hollnagel (1998). Another important definition of human error is the one proposed by Reason (1990): “Error will be taken as a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency.”

In general, the human behavior is a fundamental contributor to decrease the efficiency and safety of critical systems. However, it is important to note that one can not dismiss the human element of this interaction. Therefore, it is important to study and look for mitigate the outcomes from human error in complex systems like power hydroelectric systems.

3.1 Human Error

According to Duarte (2003), human error is responsible for approximately 70% of accidents. This fact could be see in results published by Boeing in 1989 (Duarte 2003) involving aircraft accidents; analysis of 162 false alarms at a nuclear plant in California where two thirds were caused by human error; and in the chemical processing industry, 40% of crashes involving pipe can be attributed to operator error. In one Brazilian company of power hydroelectric are committed an average of 50 human errors per year and of these 50, 11 cause serious outcomes (See chapter 5). Studies by the Brazilian Corporate Management Committee of the Power Industry have shown that in the electricity sector, 82.6% of accidents result from administrative errors, of which 63.04% are failures of supervision and planning, and 19.56% are caused by the use of improper procedures by workers. Also according to Duarte (2003), claiming that accidents are due to human error, and merely recommending that the operator is more careful, although true, does not lead to constructive actions. In fact, we need a change of attitude that is not limited to informing the executor that he/she could have done better. Upon the occurrence of a particular accident, there is only the figure of the performer, but also the need for greater awareness of risk management since the project involving the installation, even better procedures, training more appropriate, etc. that will result in taking the necessary steps to prevent it or avoid it. For it is always easier to admit that we can do better than accept the error. As human error may have different causes and effects, different actions are necessary to prevent it. The first step to analyze human error is to identify how these errors are made, or better determine its failure mode. Human errors could be grouped into two categories: slips or lapses and errors of intention named mistakes, Figure 1**.** Besides the errors of slip (lapse) or mistake, the executor may deliberately decide not to follow proper procedures. Or rather, he/she may reject the information. The errors arising from the rejection of information are named violations. The human error paths, will be best detailed in chapter 4.

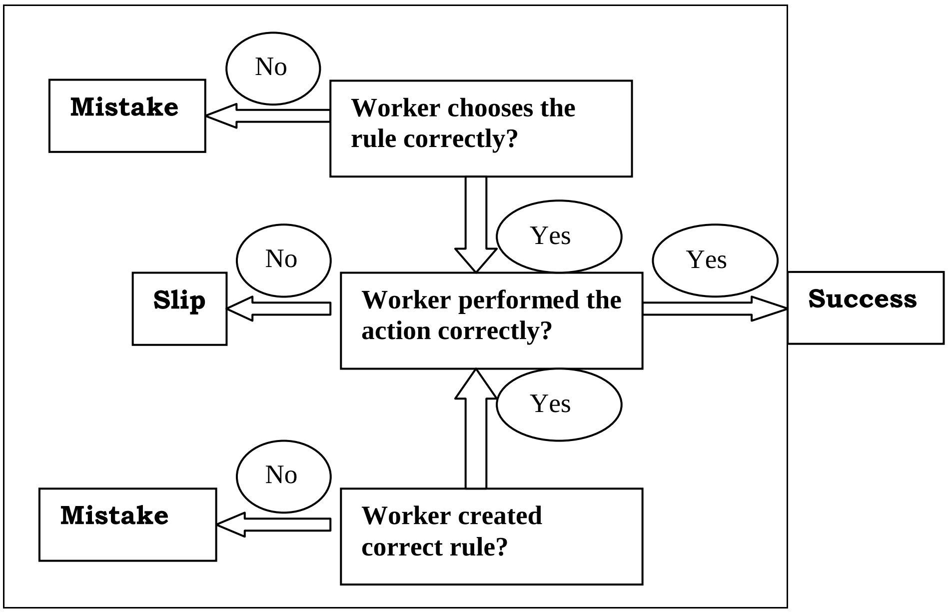


Figure 1. Categories of human errors

A slip (lapse) may occur even when the operator knows what to do and how. In other words, the error from a slip might result from a failure to perform a procedure, although the executor is qualified (has physical and mental conditions, and is appropriately trained) and has all the necessary conditions to perform the procedure successfully.

Routine procedures usually are performed without close supervision of our consciousness, like on autopilot. When, for some reason, the pilot mechanism fails, it is very likely that an error could occur. Errors of lapse and slip were studied by Reason (1990). On the other side, errors of intent (mistake) are due to badly designed procedures or poor or insufficient training. Or rather, the operator does not know how to perform the procedure although he/she thinks he knows. An error of intent can occur when the operator follows the procedures with which he could not to be familiarized. Or when an unusual situation occurs and a new sequence of actions is needed, usually during an emergency situation.

Training means giving the operator an understanding of the methodology and technology used, their responsibilities, and look for to develop their skills to diagnose faults and make decisions. It is necessary to explain the instructions and procedures for those who will run them. And this should be discussed and clearly understood for all. Even when the systems are simple to operate and maintain, its instructions are well written and sufficiently detailed, it is unlikely that these instructions and procedures can predict everything that might go wrong. It is important that the instructions and/or procedures only transmit to the operator what he/she must do or not. The instructions and procedures must prevent errors based on rules of behavior. According to Rasmussen (1999), the errors of intent should be prevented based on the development of operator skills and his/her knowledge.

The need to train the operator to diagnose and make personal decisions is important because even when the intervention to be performed is very simple and only a few procedures are sufficient, given the complexity of current systems, these procedures, even well detailed will always be incomplete and it is impossible to cover all the aspects to be considered.

Errors of intent can be reduced through proper training; however slips (lapse) errors do not. Slips error becomes evident that the practice does not lead to perfection. As the errors of intention, thus are failures in diagnosis, decision making and planning, can be avoided by giving the operator more time to think. Conversely, when an operator makes a mistake due to a slip, he/she was not necessarily under pressure, and more time to think would not matter

One of the most important aspects in a risk management program is to understand the causes of accidents and human factors that influence the operator performance. Human errors can be induced by a combination of organizational factors, cultural, technical, environmental, and others. On the other hand, some initiating events can trigger these factors into a sequence of actions that could result in an accident unless there is some kind of barrier or mitigation measures that may prevent the occurrence of human errors.

If the operator does not eat well or sleep well, he/she indeed shows fatigue signs. This fatigue can affect his/her motor performance and may also decrease his/her concentration. On the other hand, the quality of operating procedures, oral or written, may also affect the operator performance. Table 1 shows some performance factors and challenges associated with them. Later, these performance factors will be detailed. The existence of written instructions and normalized, represent an important factor for good performance of the operator during a task. According to studies in nuclear power plants in emergency situations (Duarte 2003), detailed procedures result in quicker and more correct actions. The success or failure of the performer to play a given intervention will depend on intrinsic factors, environmental and stress. Intrinsic factors are motivation (the executor wishes to perform the procedures correctly?), Temperament and physical and mental ability (the executor will be able to maintain emotional balance when subjected to an abnormal situation?), concentration (the executor is able to exclude other influences during an intervention?), response speed (the executor will respond quickly when subjected to an abnormal situation?) and knowledge (the executor has been properly trained to conduct the intervention?).

Table 1. Common question about the operator's performance. Source: Duarte (2003)

Performance Shaping Factors	**Definition**
Team expertise	What is an expertise team?
Time	How much time is needed to performance an intervention?
Stress	What kind of stress the operator is submitted to during an intervention?
Necessary procedures	The operator needs some kind of procedure to performance the intervention? Is the procedure followed by the operator?
Scope of procedures	Scope of procedures covers all tasks performed by operator?
Quality of procedure	Are the procedures in accordance with code and standard currents? Are they complex? What is the necessary level of scholar from operator to understand the procedure?
Knowledge of procedure	The operator understands the procedure? What's the intelligence quotient needed to understand the procedure? What is the level of emotional intelligence needed to understand and implement the procedure?
Performed versus written	What was performed in filed is according to written procedure?
Prevention	Is it possible to verify whether the operator performed the task correctly? How? Is it possible to introduce some kind of protection or mitigated measures that can stop the sequence of chain errors?
Interdependence	Tasks what must be executed in an intervention depend on one each other?
Dynamic issues	Are there tasks in an intervention that is executed simultaneously?
Toys and dresses	Are necessary special equipments and special tools during an intervention? They are available? They are in good state of conservation?
Behavior	Parameters such as temperature, humidity, electromagnetic fields, among others affect the performance of the operator?

Environmental factors are characterized by the physical and wheather conditions (wind and humidity) and shift work. Environmental factors also include the organizational aspects (relationship with colleagues, supervisor, manager, job satisfaction, job safety) and personal aspects such as hunger, haste, among others.

The reliability provided by the performance of an operator during an intervention in a given environment, in the organization context and/or in the physical and personal, depends on level of stress. Figure 2 shows qualitatively the relationship between human error and the stress level. It is observed that there is a level of stress to which the rate of human error is minimal. Likewise, if the operator is upset or excited, the error rate is higher. It is noteworthy that the rate of human error also tends to increase with the complexity of the task to be performed.

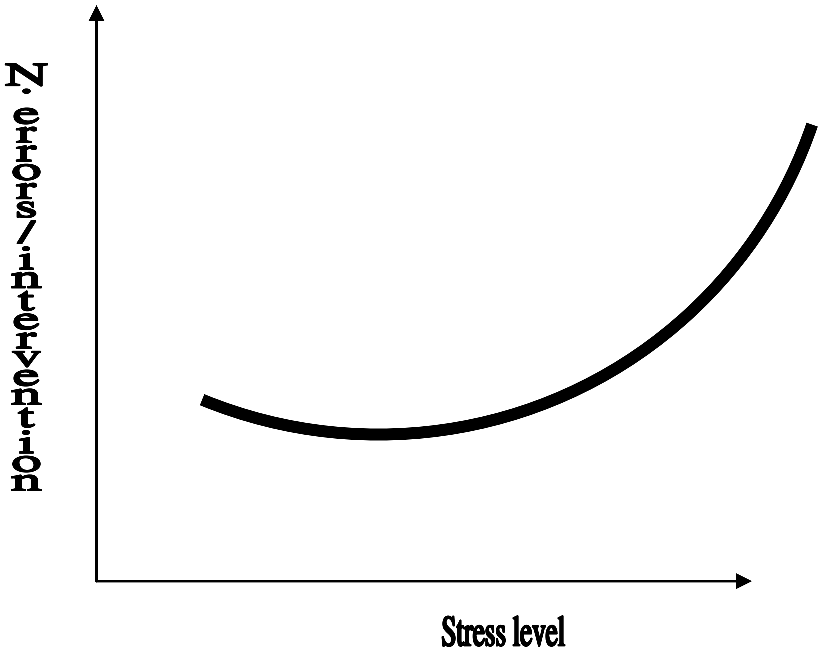


Figure 2. Stress level effect on human error rate. Source:Duarte, Dayse (2003)

3.2 Human Reliability

The most important measure of performance in assessing risk is human reliability. Human reliability analysis is an important part of risk analysis. It has long been recognized that human error has a significant impact on the reliability of complex systems. The accidents at the Three Mile Island nuclear plant and many failures of aircraft show how human error can destroy the safeguards of engineering as barriers against the dangers and play a dominant role in the progression of accidents and exposure risks. At least 70% of aviation accidents with injuries are caused by human being, according Duarte (2003), this statistic can similarly apply to shipping and industrial process. Studies on reactors safety have revealed that over 50% of the potential for accidents in the nuclear industry are related to human error. In general, the human contribution to limiting the overall hazard is as important as the reliability of equipment.

HRA (Human Reliability Analysis) has been used to study human actions and their interactions with a system, taking into account their limitations and factors influencing the human performance according to Menezês and Droguett (2005). Human reliability is the probability that a person properly run an activity required by the system within a set time (if applicable), which would not degrade the system according to Swain and Guttmann (1983). In this way, one can notice the fundamental need of resources provided by an adequate taxonomy for performing HRA; without these prerequisites, HRA would naturally become useless or inconsistent with the system being modeled.

To obtain a precise and accurate measurement of system reliability, human error must always be taken into consideration. System analysis through drawings, procedures, and reports of investigation accident have shown that human error can be the immediate initiator of the accident or can play a dominant role in the progress of undesirable events. Without incorporating the probability of human error (HEP), the results of risk analysis are incomplete and often underestimated according Duarte (2003).

To estimate HEP (and therefore the human reliability), there is a need to understand human behavior. However, human behavior is very difficult to be modeled. According Duarte (2003) literature shows that there is not a strong consensus on how to best capture all human actions and quantify the HEPs. The assumptions, mechanisms and approaches to a specific model can not be applied to all human activities. In general, human reliability models need further improvement, particularly in the capture and quantification of unintentional human error. Current limitations and difficulties in HRA predictions according Duarte (2003) are:

- Human behavior is a complex issue that can not be described as a simple machine part of a system. Human performance can be affected by social, environmental, psychological, physical which are difficult to quantify;
- Human actions can not be seen as binary states: success and failures just like with equipment failure. In addition, the full range of human interactions has not yet been fully analyzed by HRA methods. The most difficult problem with HRA is the lack of adequate data on human behavior in extreme situations;
- Human error can occur at any stage of design, manufacturing, construction and operation of a complex system. Mistakes made in the design, fabrication and construction can also be a source of errors that are committed during the operation of systems. For some human errors, the negative outcome is almost immediate, for others

situations the consequences of human error will be known only after some time. In this way, Reason and Maddox (2005) define:

Active failures are the result of unsafe acts (errors and violations) committed by those at the "sharp end" of the system (pilots, air traffic controllers, etc.). They are the people at the human-system interface whose actions can, and sometime do, have immediate adverse consequences.

Latent failures are created as the result of decisions, taken at the higher echelons of the organization. Their damaging consequences may lie dormant for a long time, becoming evident only when they combine with local triggering factors (e.g., errors, violations and local conditions) to break the system defenses.

Additional concern occurs during operation of the system because there is errors where the human remains supervise and control the performance of complex systems.

In others cases, major errors are dependent on faults whose occurrence can lead to loss of multiple barriers to hazards and redundancy in the system. Typically, quality assurance programs are designed and implemented to minimize the occurrence of these types of human error.

In the sequel, will be a literature review of some HRA approaches more important according Hollnagel (1998).

First Generation Techniques

The first models to analyze human reliability appeared in 1975, in the nuclear industry. The first-generation models are so classified because they have some general characteristics in common, such as:

Human reliability is described in the same way as equipment reliability. This hypothesis should no longer be applied, because when one analyzes human reliability, one should take into account the entire process of cognitive activity;

Binary representation of human action (success or failure): is just a specific case of the above item, because the equipment when required for an activity can provide answers to failure or success. That is, this is treating the response of the human being as if it were a machine;

Errors of omission and commission: There are the two types of errors that can occur when a person is asked to perform a task. Errors of commission are those committed in the execution of the task, while errors of omission are errors when the worker omits a step in the task;

Focus on aspects of human action: first-generation models emphasize the errors of omission and commission because they can be easily observed, but other types of errors are not handled;

Little worry with the cognitive aspects of human actions: which comes to a severe failure, because to understand properly human actions should be taken into account the cognitive aspects;

Emphasis on quantification: first generation models have the need to estimate the probability of human error (HEP) identified by event tree, as it is done for the analysis of equipment reliability;

Indirect approach to the context: how the analysis is proposed, each performance factor is independent of each other. This hypothesis is not true in practice, because the performance factors are connected with each other, as will be seen in the 2nd generation models;

$$\Pr(HEP/context) = \Pr(HEP\_basic) * (\sum PSF_i * W_i) \qquad (3.1)$$

HEP: human error probability;

HEP_basic: likely to commit the error regardless of the environment the activity is being developed

PSF: performance shaped factors;

Wi: Weight of influence of each performance factor.

The literature presents about 35 models of first generation, but this figure is questioned, because many models presented as new are just enhancements of models previously proposed. The following will be detailed the main characteristics of the model's method more discussed in literature, according to Hollnagel (1998).

Accident Investigation and Progression Analysis (AIPA)

According to Hollnagel (1998), AIPA was developed to estimate the probability of a worker response, operating a gas-cooled reactor at high temperatures. The purpose of the AIPA was to determine the probability of whether the action would be carried out, described in terms of the mean time to operator response. According to Swain (1989) the AIPA method included the following basic modelling assumtions:

- The worker had a probability of zero for making any response instantaneously – defined as the interval from 0.2 to 40 seconds after an event.
- Given enough time, the worker eventually take some action, which most likely would not increase the potential event consequences.

- If the worker found that the first action were insufficient, he would then take further corrective action until a mitigating condition was achieved. (This seems to be a very optimistic point of view!).

AIPA cannot be said to include an worker model as . The workerblack box that emits a – possibly sucessful – response according to an unknown “mechanism”.

Operator Action Tree (OAT)

The OAT or OATS was developed by John Wreathall in the early 1980s and has been described by Wreathall (1982). The OAT approach to HRA is based on the premisse that the response to an event can be described as consisting of three stages: (1) observing or noting the event, (2) diagnosing or thinking about it, and (3) responding to it. It is further assumed that errors that may occur during the third phase, i. e., carrying out the necessary response actions, are not the most important. The primary concern should rather be on the errors that may occur during the second stage, the diagnosis. The OAT approach therefore concentrates on the probability that the worker correctly diagnoses accident and identifies the responses that are necessary in terms of system operations.

Technique for Human Error Rate Prediction (THERP)

According to Hollnagel (1998) THERP is probably the best known technique presented as the 1st generation. The aim of THERP is to calculate the probability of successful performance of the activities necessary for the accomplishment of a task. The calculations are based on pre-defined error rates (the so-called HEPs), and success is defined as the 1`s complement to the probability of making an error. THERP involves performing a task analysis to provide a description of the performance characteristics of the human tasks being analysed. The result of the task analysis are represented graphically in an HRA event tree that is a formal representation of the required sequence of actions. The nominal probability estimates from the analysis of the HRA event tree are modified for the effects of sequence-specific PSFs, which may include factors such as dependence between and within workers, stress levels, experience, quality of information provided, display types, etc.

The basis for applying THERP is a schematic representation of human actions and related system events, the so-called HRA event tree. The method consists of the following six steps:

- Define the system failures that can be influenced by human error and for which probabilities are to be estimated.
- Identify, list, and analyse human operations performed and their relationships to system tasks and funtions of interest.

- Estimate the relevant human error probabilities.
- Determine the effects of human errors on the system failure events of interest.
- Recommend changes to the system in order to reduce system failure rate to an acceptable level.
- Review the consequences of proposed changes with respect to availability, reliability and cost-benefit.

Human Cognitive Reliability (HCR)

According to Hollnagel (1998) the basis for the HRC approach is actually a normalised time-reliability curve, where the shape is determined by the dominant cognitive process associated with the task being performed. The analyst determines the type of cognitive process, estimates the median response time and the time window, and uses the HRC model to quantify the non-response probability.

The HCR method can be described as having the following sis steps:

- Identify the action that must be analysed by the HRA, using e. g. a task analysis method
- Classify the types of cognitive processing required by the actions. This classification in itself uses a sequence of binary choices, resulting in a classification in terms of skill-based, rule-based and knowledge-based actions according Rasmussen (1982).
- Determine the median response time of a crew to perform the required tasks.
- Adjust the median response time to accont for performance influencing factors.
- For each action, determine the system time window in which action must be taken.
- Finally, divide the system time window with median response time to obtain a normalised time value. On the basis of this, the probability of non-response is found using a set of time-reliability curves.

The median response time is obtained from simulator measurements, task analysis, or expert judgement. The effects on crew performance of operational-induced stress, control room equipment arrangement, etc., are accounted for by modifying the median time to perform the task.

Maintenance Personnel Performance Simulation (MAPPS)

According to Hollnagel (1998) the MAPPS computer model was developed to provide a tool for analysing maintenance activities in nuclear power plants. A principal focus of the model is to provide maintenance-oriented human performance reliability data for PRA purposes. The influence of select PSFs is also included, such environmental, motivacional, task, and organisational variables. The output from MAPPS provides information about predicted errors, personnel requeriments, personal stress and fatigue, performance time, and required ability levels for any corrective or preventive maintenance actions.

Socio-Technical Assessment of Human Reliability (STAHR)

According to Hollnagel (1998) STAHR differs in many ways from other approaches of the 1st generation of human reliability. The consensus of this method is based on a psychological scale to assess human reliability in complex technical systems, and consists of a technical and social component. The technical component is a diagram that shows the influence of the network of causes and effects, factors linking the outcome of the situation. The social component refers to the discovery, by group consensus, the experts' judgments of conditional probability of various factors shown in the diagram of influences as well as their respective weights of evidence.

Analyzing the first-generation methods, Hollnagel (1998) listed some common shortcommings, such as:

- Data less than adequate: Due to shortage of human performance data that are useful to quantify human behavior in complex systems;
- Misunderstanding the use of the judgments of experts in the methods, so far no one has satisfactorily demonstrated the level of consistency among the experts, let alone the accuracy of prediction;
- Difficult calibration of simulation data, such as simulators are not the real situation, there is a problem as it should be done to transform the simulation data for the real world;
- Psychological reality less than adequate in some approaches to HRA: many approaches to human reliability analysis are based on highly questionable assumptions about human behavior;
- Less than adequate treatment of some important performance factors.

Second Generation Techniques

First-generation models have several weaknesses, as have been previously presented. The first-generation models must not be viewed as methods for estimating the value (number) for human reliability, but it allows us to assess the impact of action and compare different alternatives. Therefore, 2nd generation models have emerged in order to overcome these shortcomings. Second-generation models are still emerging, and there is little consensus about what they are. This is mainly because they were defined in terms of what should not be. The following will be a description of the main tecniques found in literature.

Cognitive Environment Simulator (CES)

According to Hollnagel, CES is a tool developed for computer simulation analysis. This tool was used to explore the intentional formation of man. So, instead of defining theoretically the possibility of error mode, CES will create it by simulation, taking into account the characteristics of the simulation. The goal of the CES is to see how the worker will respond to a given situation. The input data of the simulator is a set of values that correspond to a given situation in the plant. These values are generated by process simulation and provided via a display. The values read on the display are used to produce the intent to share in a given situation. This intention to return the process simulator, which generates new values for the CES.

The CES has three types of activities during a session:

- The system state is monitored via a display;
- The explanations are generated to account for the observations, particularly when some event happens. These explanations make use of a detailed knowledge-based process;
- The CES finally selects the appropriate responses (intentions for action). Each action is intended to correct an abnormality of the system and adapt pre-planned responses to unusual circumstances.

As CES generates intention in action instead of individual actions, it does not have a classification of errors or wrongful actions explicit. He obviously can generate intentions are wrong, but the classification is more subtle than the binary classification models typically used in 1st generation. The CES does not provide estimates of probabilities of specific actions and there is no need to classify actions as successes or failures. The CES is several ways to generate actions that the worker is likely to play under different operating conditions. The classification of actions is better in terms of possible strategies for solving problems. The model used in the CES worker is well detailed and is adapted from a model of artificial intelligence (EAGOL). This model can use several strategies to solve problems.

Intent

According to Hollnagel, the background for the development of INTENT was the recognition that THERP only treats a few “errors of comission”, namely “errors of selection” and “errors of execution". It was felt that there was a need to enlarge the scope to cover other types of commission errors, notably "errors of intention". On the surface, INTENT therefore addressed the same issue as the CES

The method describes only the steps necessary to determine and quantify the probabilities for errors of intent. The same basic method is applied to THERP. The steps below are used in INTENT:

- **Compile errors of intention:** This was done by observing errors of intent from two sources of data, and NUCLARR READ. The category defined by intention includes consequent action, response adjustment, attitudes, and sources of dependencies;
- **Quantify the errors of intention:** This was achieved by a method of direct estimation, which includes HEP to determine the lower and upper band, as well as performance factors and their respective weights;
- **Determine composite PSFs:** Each PSF was rated on a site and scenario specific basis on a scale from 1 to 5, where a low value corresponded to an unfavourable rating. The composite PSF for each error type used the common principles of multiplying and summing;
- **Determine site specific HEPS for intention:** Finally, the site specific HEPs were calculated using a specially developed equation.

Only step 1 is specific for INTENT, and even this is generic in the sense that "errors of intention" can be replaced by another error type.

Project on Methods for Addressing Human in Safety Analysis (EPRI)

The structure of the method is similar to those applied in the first-generation techniques, as mentioned previously here in this section, but the difference is the emphasis on the specific steps listed below:

- Identifying expressions of errors: This model recognized the need to use a combination of modes of errors, making them more complete instead of using only the traditional, omission and commission errors. Thus, diagnostic errors are errors in the different expressions of PSA event tree;
- Characterization of performance shaping factors (PSFs): This model also clearly recognized that the PSFs should be described at a level relevant to the ways of error. Thus, the effects of PSFs could be directly included in the qualitative analysis.

The classification scheme presented in detail the ways of their errors, and their possible causes. The modes of errors were grouped according to the model structure of the worker. Therefore, the classification scheme is based on the model of the worker. The model used in the EPRI worker, was a simple processing model composed of three modules: Information, Decision and Action was set up a graphical notation used to explain the possible combinations of information processing that may correspond to modes of typical errors. The model of the worker has the virtue of simplicity. However, it is extremely important that the project explicitly considers not only the ways of error, but also the PSFs.

A Technique for Human Error Analysis (ATHEANA)

According to Hollnagel, the purpose of ATHEANA was to develop a model of human reliability analysis that could improve the ability PRA/PSA to identify important interactions between man and system, represents the most important sequence of the accident, and provides recommendations for improving human performance based on analysis of possible causes. The method used by ATHEANA is clearly described, and can be represented graphically in Figure 3, which is summarized in the following steps:

The method begins by identifying possible Human Failure Events (HFE), which are described by the event tree PRA / PSA. These events are characterized in terms of unsafe actions (slips, lapses and mistakes);

At this stage, we consider the Error-forcing Context (EFC) system, which is defined by the combined effects of the PSFs and the conditions that cause human errors.

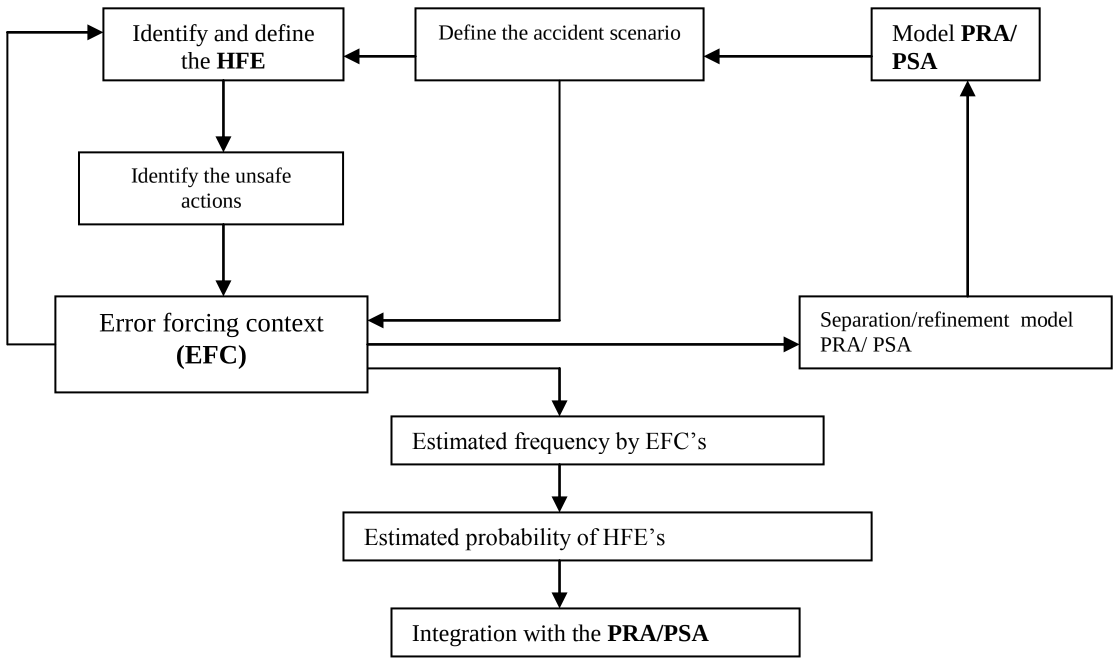


Figure 3: The ATHEANA Method. Source:Hollnagel (1998)

ATHEANA has two major loops. The first loop is a characterization of EFCs to identify the HFEs. This loop recognizes that an improved description of the context may be sufficient to identify the best HFEs and can correct the flaws of an inappropriate context. The second loop is a characterization of the model for CME PRA / PSA. This loop suggests that the qualitative result of the HRA can be used to modify the base model, thereby improving the conditions of human-system interaction, which may be missing in the first part.

The final quantification is done according to the following expression:

$$P(E \setminus S) = \sum_{asi} \sum_{epcj} P_{ij}(S) \qquad (3.2)$$

where: P(E\S): is the probability of the HFE in scenario S and $P_{ij}(S)$ is the probability of unsafe action$_i$ resulting from EFCj in scenario S.

ATHEANA uses the classification scheme in two different ways. The first is in compliance with the PRA / PSA traditional distinction between omissions and commissions as HFEs basic. The second is related to the characterization of Reason (1990) for unsafe actions for improvement of basic HFEs. Although ATHEANA recognizes various recent developments in cognitive psychology and cognitive engineering, this technique does not go very far in terms of classification scheme. As for the model worker, ATHEANA make a link between the CME and HFEs, referring to the information processing model with the following stages, detection, situation assessment, response planning, and implementation of the response.

Cognitive Reliability and Error Analysis Method (CREAM)

According Hollnagel (1998), unlike most first-generation methods, CREAM is based explicitly on a set of principles of cognitive modeling. The basic notion is that of modeling contextual control, that is, describing human cognition in terms of responsibility for the actions and the way in which actions are controlled - with a simple model of cognition (SMoC) or a contextual control model (COCOM) more detailed. This is combined with a detailed list of actions. The classification describes the relationships between causes and effects by defining a number of subgroups or tables. Tables are provided by way of errors, cognitive functions required by the model, and causes general system and organizational. In each table, the causes and consequences are subdivided into general categories and specific. This enables the analysis to occur in different levels of detail, reflecting the quality of information available.

CREAM is divided into two stages of analysis that are complementary to each other, which will be discussed below:

CREAM – Basic Method

The purpose of the basic method is to provide an overall assessment of the reliability of performance expected of the task. The evaluation is expressed in general terms of probability of failure of actions, that is, an estimate of the likely performance of a wrong action for the task as a whole. This method can be divided into three steps:

- Description of task to be analyzed;
- Evaluate common performance conditions (Common Performance Conditions - CPCs);
- Determine the possible mode of control (control mode).

For a description of the task should be to use a systematic method, such as Hierarchical Task Analysis - HTA and Goals - Means Task Analysis - GMTA.

The basic method considers a list of nine CPCs, which are, adequacy of the organization, working conditions, adequacy of man-machine interface and operational support, availability of procedures / plans, number of simultaneous goals to be achieved, time available, period days, adequacy of training and experience, and team collaboration for quality. Check each CPC as an influence on performance for the task, and may "improve", "reduced" or "not significant" for the assignment. There are four types of control modes considered: the strategic, tactical, opportunistic, and "dispersed" (scrambled). To find out which mode of control is the task, it is the sum of the number of CPCs that "improvement" and that "reduces" the performance of the task. Through a graph are related to these sums and the type of control mode considered. As can be seen in the Figure 4:

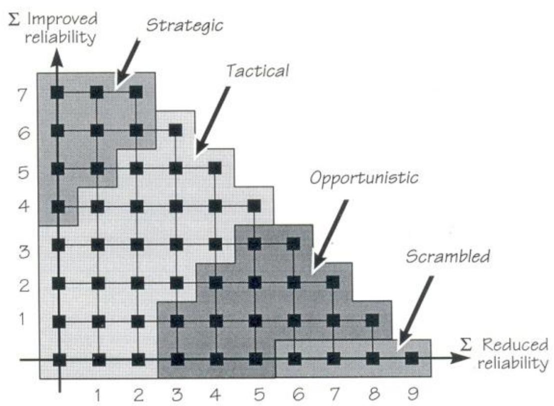


Figure 4: Improved x Reduced reliability. Source:Hollangel (1998)

For each type of control mode there is a range of probability of error associated action.

CREAM – Extended Method

The purpose of this method is to produce the probability of failure of a particular action. The method is based on the fundamental principle that the odds of failure are identified through the features of the task as a whole, that is, the action takes place within a context and not in isolation. The execution of the method consists of three steps:

- Building a profile of cognitive demand of the task;
- Identify the likely failure of cognitive functions;
- Determine the probability of failure of specific action.

For the construction of the cognitive profile should first relate each activity a task with pre-defined cognitive activity. And in turn, each cognitive activity is related to cognitive function of the model. Table 2 shows the relationship between cognitive activities and cognitive functions of the model.

Table 2: Cognitive activities and cognitive functions

Cognitive action	**Cognitive Functions of COCOM**			
	Observing	Interpreting	Planning	Executing
Coordinate			x	X
Communicate				X
Compare		x		
Diagnose		x	x	
Assess		x	x	
Execute				X
Identify		x		
Maintenance			x	X
Monitor	x	x		
Observe	x			
Plan			x	
Remember		x		X
Regular	x			X
Copy	x			
Check	x	x		

For each type of errors are associated with cognitive function, and according to the distribution of these errors is possible to determine the profile of task failure, that is, this profile will indicate the most frequently used cognitive functions and activities most likely to occur at fault. After mounting the cognitive profile should determine the probability of failure of action, which is performed through three steps:

- Determine the probability of cognitive failure nominal (Cognitive Failure Probability - CFP) for each of the probable values of a failure of cognitive function;
- Correct values CFP's with CPC's;
- Incorporate the adjusted value of the CFP in the tree of events.

The probability rating of cognitive failure can be found through in Swain & Guttman (1983). The correction of nominal values of CFP's is done through the CPC's weights measured, according to the level of interference with each CPC that the error associated with cognitive function.

IDAC - Information Perception, Diagnosis and Decision Making, and Action Taking in Crew Perspective. *Chang & Mosleh (1999).*

The concept of developing the IDAC operating crew behavior model is seeing the system and operating crew as an integrated system, as the circle surrounding these two blocks shown in Figure 5.

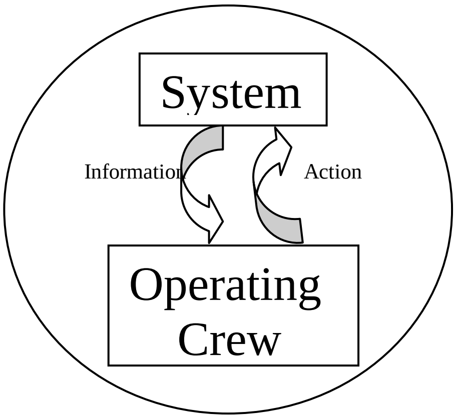


Figure 5: IDAC perspective of viewing system and operating crew as an integrated system.
Source: Cheng & Mosleh (1999)

This tight connection between the system and the operating crew, modeled in IDAC, becomes clear at the concept of developing the behavior (cognition and action) rules. The IDAC models the "rational" or "expected" industrial workers cognitive behavior only. Irrational behaviors are out of the scope of IDAC. The rational behaviors are the behaviors that the worker has desire of doing or not doing them irrespective the correctness of the motivations whether the actions are carried out as intended. Based on the definitional, even the consequence is not desired, the workers' behavior of the TMI accident is "rational". The examples of irrational behaviors are behaviors under drunk or drug. The methodology was implemented as part of a more comprehensive platform for conducting a dynamic PRA. The Accident Dynamic Simulator (ADS) models multiple workers, function as a team, interacting with their surrounding objects, which include the system, the other workers (teammates), or the external resources (e.g., consulting personnel not in the working team). IDAC models an individual worker's behavior, in a teamwork environment, interacting with the system, and the worker's behavior is influenced by four groups of factors: external factors, organizational factors, team-related factors, and individual-related factors. The four-group classification is "blunt" classification since in some cases it is hard to draw a clear line between different groups. In such situation, the task of classifying a factor in one group but not the other becomes uneasy.

The external factors are the unexpected working environment such as the unexpected harsh environmental conditions or system hidden errors. The organizational factors are the task-related factors affecting individual behavior that, in common sense, can be controlled by management. For example, the quality of man-machine interface, work (safety) culture, procedural availability and quality etc. The team-related factors reflect the different aspects of the crew interacting and functioning as a team. For example, the backup, mutual performance monitoring, error detection, and error correction etc. are in this category. The individual-related factors are the individual psychological (e.g., stress) and physiological related factors. All the factors in these four groups, which eventually influence a worker's behavior, are called as performance shaping factors (PSFs). Locating a PSF in its appropriate group is based on the PSFs proximate impact on the individual and the level of detail of the analysis interest. See Figure 6 to understand the relation among these factors.

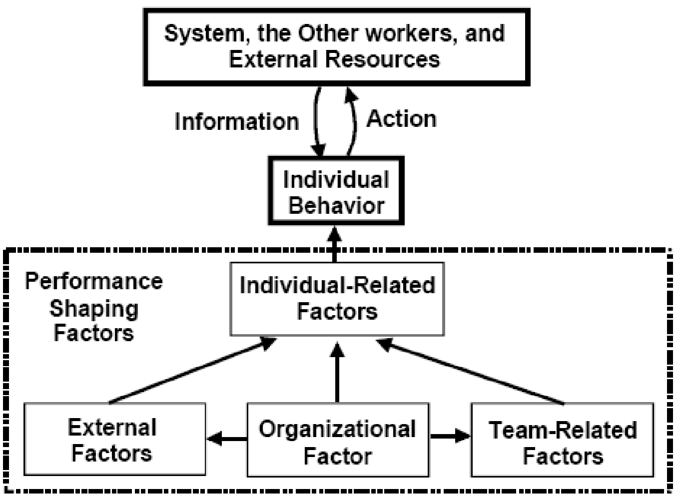


Figure 6: An overview of the performance influencing factors influencing an individual worker behavior and their dependencies, and the interaction of an individual worker interact with the surrounding objects. Source: Chang & Mosleh (1999)

In IDAC, like in most second generation models, the mental state of the worker is relevant to assess the human error. IDAC models Mental State (MS) by dividing the gestalt of psychological character into three stages. The first stage is the perception and appraisal of the external world. The second stage is the generation of the stimulus and the specific covert feeling. The final stage is the mood or the overt psychological behavior. Another component affecting MS is the inertia relating individual's intrinsic characteristics. Figure 7 shows the influencing diagram of a worker's behavior.

In Figure 7**,** three blocks including the MS, WM, and the physiological factors are the individual related factors. The other three blocks in the bottom are the factor external to the individual which including the team related factors, organizational factors, and external factors. The top of Figure 7 shows that the individual behavior eventually must be affected by the individual related factors. The factors external to the individual must affect the individual related factors in someway, and that could be memory, MS, or physical factors. Perceived raw information is temporarily stores in the WM that serves as the stimuli to change the MS. The stimuli is amplified or damped after passing through the worker's intrinsic psychological characteristics then be appraised. Feelings are generated in response to the appraisal and, eventually, revealed as the mood of the worker, which can be sensed by the other workers. Although the stream of feeling go through the three stages (perception and appraisal, stimulus and feelings, and mood), however, the worker's behavior (on the top of Figure 7) could be influenced by any factor directly. For example, unavailable procedure (represented by the factor of the availability of procedure of the organizational factors) prevents the worker from using procedure to solve the problem. It is a complex issue to clarify the paths of influence of the reified MS element shown in Figure 7. For simplicity reason, a factor could influence the factors at higher level but not below or at the same level. According to the flow diagram of the worker cognitive behavior, the MS is updated constantly and equity. The worker behavior affected by the high-level MS elements could affect the information perception. Different perception of the new information could affect the low-level MS elements. Thus, even though only the bottom-to-top influence are considered, in the course a scenario both bottom-to-top and top-to-bottom influences are considered. A significant number of studies have been reviewed to identify the completeness of the factors in each group. Introducing the technique in more practice form, according to Menêzes and Droguett (2005), this methodology consists of coupling the IDAC models with tree events. From an initiator event, attempts to model the operator behavior in a dynamic system.

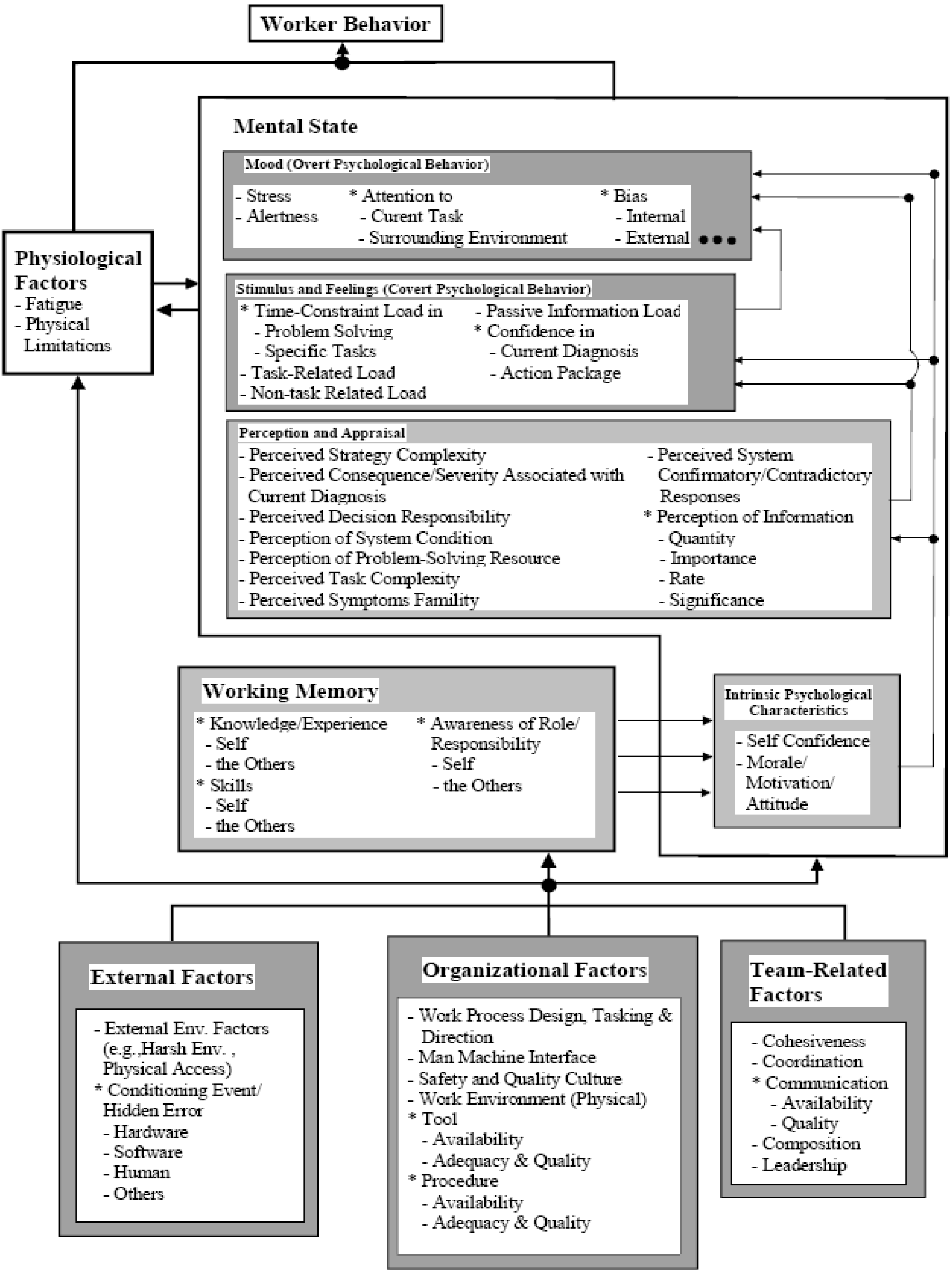


Figure 7: The Hierarchical structure of human behavior influencing factors, and their paths of influencing. Source: Chang & Mosleh (1999)

Through the event tree, it is possible to see the different stages of the cognitive model IDAC, and alternatives of choice that the operator has in each stage. Each alternative model is influenced by PSFs which receive a weight set by experts or by an equation that reflects dependencies between the factors and different types of influence (direct or indirect). At each stage of the model, the factors are updated, i.e., the factors of the stage of perception are not the same factors of the action performed. Once defined, by experts, the weights of each alternative, the probability of an alternative is calculated by dividing the weight of this alternative by the sum of the weights of all alternative of the stage considered. Finally, by multiplying the probabilities of belonging to a same path of the tree, it is possible to find the probability of a given sequence of the tree.

$$P1 = P(Perceived) \times P21 \times P31 \qquad (3.3)$$

See Figure 8

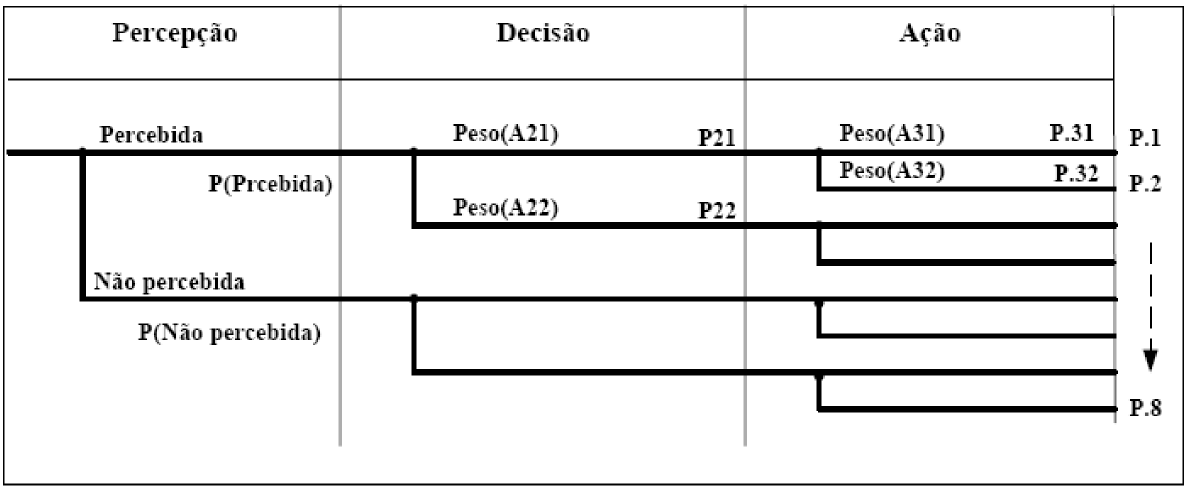


Figure 8: IDAC methodology. Source: Menezês & Droguett (2005)

This new technique, seen as an advancement of 2nd generation techniques, looks for details all factors that influence human performance during the execution of tasks in a control system, as well as quantify their cause and effect relationships. This technique is based on findings from relevant areas of cognitive psychology, science behavior, neuroscience, human factors and others. According to Chang and Mosleh (1999), on occurrence of an abnormal event, the natural reaction of a person, usually includes physical consequences (fatigue, nausea, tremors muscle, etc), cognitive effects (memory impairment, difficulty in decision making, confusion, etc.) and emotional consequences (anxiety, frustration, helplessness, etc.). These reactions are interdependent and affect the behavior of the worker.

The influence diagram shown in Figure 8, proposed by the IDAC model, shows cause and effect relationship between factors. This diagram shows a trend towards relationship much more stochastic than deterministic because stochastic models have one or more random variables as input; these inputs lead to random outputs, which can only be considered as estimates of the true characteristics of a model, while deterministic models have a known set of inputs that result in a single set of outputs. Moreover, the diagram has a set of random variables that describe the evolution of a process in time (mental state); this is the true definition of a stochastic process. The relationship assumed in this diagram is based on the development of available empirical and theoretical models, event analysis, simulations, as well as in other reviews researchers and clinicians expressed in the literature on HRA. The mental state records the mental and psychological evolution of an operator during the course of an event. Chang & Mosleh (1999) say that the mental state represents the combination of cognition and emotion, and these are two continuous, parallel and independent processes. The mental state is divided into five levels grouped hierarchically to represent the mental and psychological process. These five levels represent different stages of mental and psychological states. The following description relates these stages.

When the worker receives a stimulus or information from the outside world, its activity mind is triggered to “assessment the situation”. However, this evaluation can vary from person to person due to individual differences. The group “internal factors” represents some aspects of such differences, which may affect the quality of perception. Personality involves: morale, motivation, attitude, and confidence, among other features intrinsic to individual. The perception and evaluation result in situational awareness. This awareness causes specific sensations undeclared represented by effort and sensations. The PSFs in this phase represent the specific sensations and related to an internal situation. This phase involves, for example, feeling an excessive workload, feeling insufficient time to complete the task, among other sensations. The stage of “effort and feeling” active some effects declared represented by phase: “emotional stimulation”. The PSFs in this phase represent the aggregate effects on feelings of a situation, which are revealed and can be felt by other workers. This involves, for example, stress from frustration, pressure, conflict and uncertainty. Finally, the PSFs in cognitive ways and trends represent cognitive patterns of worker resulting from state of the other phases. A practical example of the stages of mental state can be given when the worker perceives, for example, the amount, intensity and importance of the task and therefore feels that the time is insufficient to accomplish it. This feeling provokes an emotional stimulus revealed by stress, which can come from pressure. Depending on the level of stress received, the worker may be or may not be to their level of adequate attention. The mental state also receives influences of psychological factors and information memorized. The psychological factors are all factors related to performance ergonomic compatibility and physical endurance of workers. These factors involve: fatigue, physical limitations, among others. The stored information refers to the quality of information and motor skills of the worker, as for example: knowledge of rules, experience, skills and memories of long and short term. Regarding the practical example given, the experience and skill of the worker can make a big difference, because once present, it is possible that the level of stress felt by the worker is irrelevant, not compromising their level of attention. Therefore, the information stored may affect the assessment that the worker makes the situation after having realized a new input of information. Psychological states (represented in mental status) and physiological states are interdependent. For example, fatigue cans loss of vigilance. On the other hand, lack of motivation can increase the level of fatigue. It is important to realize that external factors affect all factors related to individual (psychological, mental status and stored information). External factors involve environmental factors (physical access, discomfort of environment), event conditions (software, hardware), organizational factors (environment work, availability of tools), work team factors (leadership, unity, among others). The factors presented in Figure 8 can be classified as static or dynamic, depending on the context and applications. If the task is performed in a relatively small period, one can consider that the psychological, environmental constraints, organizational and group are static, while the internal factors individuals are sensitive to changes in even short periods of time.

The most remarkable features of this technique are as follows:

- Findings of the relevant areas of cognitive psychology, science behavioral neuroscience, human factors, among others;
- Consider the relationship of dependency between the majorities of PSFs; with the exception of interdependent relationship between external factors, which also have a relation of cause and effect, for example, the organizational can influence the quality of team communication, as well as in equipment design. Likewise, the psychological factors also have a relationship interdependence, which was disregarded in this model;
- Do not allow to quantify the influence of two workers, not considering interaction;

Given the difficulty in using event trees to model the dynamic of a system, the influence of an event in another is not considered. 1st and 2nd generation HRA techniques, as well as the IDAC model presented deficiencies rendering them not sufficiently effective and need of an evolution bring significant improvements to the human interface system. Therefore, it is clear to model the existing causality in human action has become a major challenge for HRA over the years and therefore, the development of a methodology for assessing human reliability is extremely necessary.

Human Reliability Analysis using Bayesian Networks (BBN)

In 2005 Menezês, R, C & Droguett, E. L. presented a model using Bayesian Networks to quantify the human error. This model is presented here with more details.

It is clear that modeling of causalities in human actions has become a great challenge for HRA. This model describes a methodology for modeling human actions through Bayesian Belief Networks (BBN). The methodology provides a greater flexibility as not only allows for a more realistic representation of the dynamic nature of man-system and man-man interface under normal and abnormal process states, but also represents the relationship of dependence among the events and performance shaping factors. It clearly models human actions, as well as the methods used to build the network, with emphasis on the Bayesian networks quantification mechanisms. The flowchart in Figure 9 systematically presents a methodology for HRA.

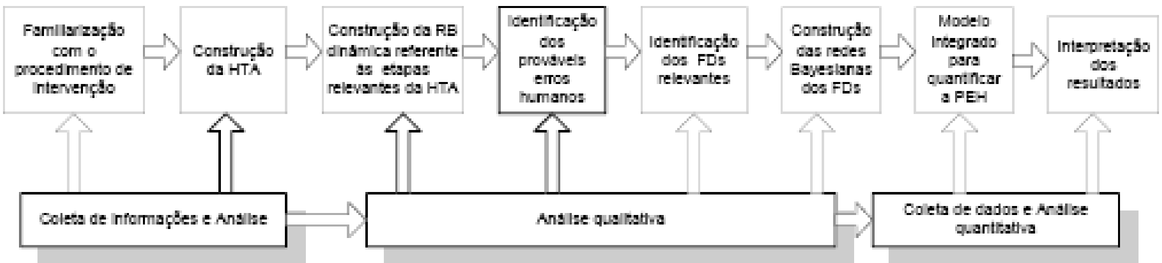


Figure 9: Flowchart of methodology. Source:Menezês & Droguett (2005)

The mains processes are described as follows:

Familiarization with the intervention procedure: this step corresponds to obtaining the necessary knowledge about the intervention procedure to describe the task (the next step flowchart). This knowledge is acquired through the study of labor standards of the company and through observations of the procedure in practice. At this stage, the contest, i.e. conditions or circumstances on which the intervention procedure occurs is also analyzed. From the context are extracted factors that somehow alter the performance of the workers involved in the intervention, these are the PSFs.

Construction of the HTA: the information acquired in the previous step, related to the intervention procedure will be described and organized by HTA (Hierarchical Task Analysis), which is a methodology that systematically describes tasks. The above steps comprise the initial phase of this method that is, collecting information and analysis. The next steps correspond to the qualitative analysis of information received through the modeling of human actions via Bayesian Networks (BN).

Construction of the dynamic Bayesian Network regarding the relevant HTA steps: this step will be identified the critical steps of HTA in terms of danger to the workers involved. From these steps, will be build the dynamic Bayesian Network of the task, which represents the actions of workers through different scenarios and sequences, while allowing a visualization of the interaction between them.

Identification of the likely human error: through the constituent's scenarios of the Bayesian Network of the task and knowledge gained in the initial phase, it is possible to identify the probable errors of each worker, as well as the consequences associated with them. This identification enables a better understanding of the behavior of workers, allowing through the reported probable human error, are known their likely causes.

Identification of relevant PSFs: once identified the likely human errors is possible to identify the probable factors responsible for such errors. At this stage, will be identified each relevant PSFs for each worker involved.

Construction of Bayesian Network of PSFs: this step will be identified relationships cause and effect between the factors selected in the previous step. Later, will be constructed a Bayesian Network for each specific role assumed by workers in intervention. The next steps correspond to the data collection for quantitative analysis by modeling of human actions via BN.

I**ntegrated model to quantify the likelihood of human error (HEP):** this stage will be held the integration of BNs from PSFs with the BNs of the task. So, each worker represented by a node in the BN of the task will have his/her BN regarding his/her relevant PSF. Later there will be the "eduction" process to obtain the conditional probabilities needed to mains supply for the intergraded model.

Interpretation of results: data from the "eduction" process will be modeled to obtain the HEPs, which will be interpreted in this step.

3.3. Human Error Taxonomy

One of the main challenges to analyze the occurrence of human error is the need of a formal language to standardize the concepts, i. e. a framework to link common code between multiple projects. In fact, it is the main target when developing taxonomy. The subject of interest is thus to homogeneously classify errors to provide adequate data to be compared and/or aggregated for analytical studies. In an effort to evolve with this theme, Rasmussen (1982) presents a framework to discuss the worker behavior characteristic, during a performance task, in three domains:

Skill-based, tasks that require manual skills; “In the skill-based domains, including automated, more or less subconscious routines, performance is controlled by stored patterns of behavior in a time-space domain. Errors are related to variability of force, space or time coordination”;

Rule-based, tasks based on predefined procedures, require training; “The rule-based domain includes performance in familiar situations controlled by stored rules for coordination of subroutines, and errors are typically related to mechanisms like wrong classification or recognition of situations, erroneous associations of tasks, or to memory slips in recall of procedures”;

Knowledge-based, complex tasks, require decision and attention; “The third behavioral domain is called upon in case of unique, unfamiliar situations for which actions must be planned from an analysis and decision based on knowledge of the functional, physical properties of the system and the priority of the various goals. In this domain, the internal data processing functions used for the task are very person and situation dependent and vary with details in the task context, with the extent and type of knowledge immediately available to the person, and with his/her subjective preferences. In general, errors in this domain can only be defined in relation to the goal of the task and generic error mechanisms can only be defined from very detailed studies based on verbal protocols which can supply data on the actual data process”.

This taxonomy proposed by Rasmussen (1982) classifying the human error in three domains had emerged as a promising way for classifying these kinds of events. However, a criticism to be made to such alternative concerns of this generality in the sense that the resulting classification does not achieve the causes of human error, an important information for dealing with complex systems like the power ones. It was yet necessary a deeper analysis to understand the worker behavior during a performance task that produced a human error in an intervention in power hydroelectric systems, for instance.

In response to this claim, in 1990, Reason presented a classification deeper than the Rasmussen's one. He proposed a taxonomy based on the worker behavior during a performance task based on cognitive characteristics. "Three distinctions have proved useful in identifying the various origins of less than adequate (LTA) performance. Such distinctions are also important since different types of human error have different psychological origins, occurring in different parts of the system, and requiring different methods for remediation" according to Reason and Maddox (2005). Reason firstly proposes two ways in which this error can occur: slips and mistakes.

Slips: "First, the plan of action may be perfectly adequate, but the actions do not go as planned. That is, we planned to do the right thing, but something happened that prevented us from doing it properly. Some necessary act(s) may be omitted or an unwanted act(s) may intrude. Alternatively, the right actions can be carried out, but in the wrong order, or in relation to the wrong objects, or poorly timed, or clumsily executed. These are execution failures and are commonly termed slips, lapses, trips, or fumbles" according Reason and Maddox (2005).

Mistakes: "The second potential locus of error is in the planning itself. Actions may go entirely as planned, but the plan itself is not adequate to achieve its intended outcome. These are higher-level failures, termed **mistakes**, associated with the formulation of the plan." according to Reason and Maddox (2005).

"Slips and lapses are errors which result from some failure in the execution and/or storage stage of action sequence, regardless of whether or not the plan which guided them was adequate to achieve its objective", Reason (1990). The main difference between slip and lapse is that whereas slips are observable as externalized actions not as planned, lapses involve failures of memory. "Mistakes may be defined as deficiencies or failure in the judgmental and/or inferential process involved in the selection of an objective or in the specification of the means to achieve it, irrespective of whether or not the actions directed by this decision-scheme run according to plan" Reason (1990). Derivate in large part from Rasmussen's classification, Reason proposed a conceptual framework – the generic error modeling system (GEMS), integrating the skill-rule-knowledge classification from Rasmussen with the slip-lapse-mistake from Reason. Using this framework, Reason subdivides the human error behavior in a sort of deeper modes of failure to characterize the error. Reason and Maddox (2005) define modes of failure: "in that errors arise from being in the wrong control mode with respect to current demands of the task. That is, the higher levels of the cognitive system are running open-loop (in relation to the moment-to-moment control of the actions) when they should have been closed-loop, and conversely". Analyzing the worker behavior when he is erring, it is possible to classify this behavior according to the Reason's framework. See table 3.

Table 3: Human Error taxonomy by Rasmussen/Reason source: Reason (1990)

Domain	**Type**	**Failure modes**	**Descriptions**
Skill-based	Slip	Double capture slips	Performing a routine task or in a family environment, at the time of decision making, some external or internal event diverts attention from the operator who makes the decision automatically, by force of habit.
	Slip	Omission following interruptions	When performing a routine task, the operator is interrupted by an event and when he returns to resume what he was doing, he can not remember at what point he was before the break, failing to execute a step.
	Slip	Reduced of intentionality	The operator has a goal to achieve, but for some reason, he forgets the proposed objective
	Slip	Perceptual confusions	Operators perform tasks without paying due attention to what they are doing
	Slip	Interference errors	Is presented in the form of "mixing" of speech, action or implementation of actions within the same sequence, producing a behavioral mixture
	Slip	Omissions	The operator, while performing a task, omits the next step that he should perform for the task, or he can omit all the accomplishment of the task from a certain point. This usually occurs when he failure checking the state between two actions. This is required to determining when the first action is completed and the next should start.
	Slip	Repetitions	This type of behavior occurs when an error is assumed that a task is not as long as it really is and the step between the assumed location and the current location (within the sequence of

			action) is repeated.
	Slip	Inversions	The original sequence of the task is reversed.
Rule-based	Mistake	Firsts exceptions	In the first time that the operator is faced with an exception to the general rule that he had always used, and as the general rule has been applied successfully in the past, he tends to apply it to the situation exception, leading to error.
	Mistake	Sings, countersigns and non signs	The operator is faced with ambiguous situation, as the presence of correct signals to trigger a given action, as also countersigns, to not trigger and also to the lack of signs, sometimes simultaneously, which leads to error.
	Mistake	Informational overload	The abundance of information is sometimes undesired, because the local state indication almost invariably exceeds the operator cognitive system ability to apprehend them, which can lead to error.
	Mistake	Rule strength	When a rule, this rule became a strong rule, and the operator can trigger this rule when some but not all conditions are satisfied.
	Mistake	General rules	General rules are likely to be stronger
	Mistake	Redundancy	It has long been known that the acquisition of human skills depends critically upon the gradual appreciation of the redundancy present in the informational input. In fact, certain sequences or grouping of signs tend to occur with redundancy, and this can lead to error.
	Mistake	Rigidity	The operator tends to reapply, over and over, a rule that achieved successful outcomes at the past.
	Mistake	Encoding deficiencies	Certain properties of the problem space are not encoded at all.

			Certain properties of the problem space may be encoded inaccurately; An erroneous general rule may be protected by the existence of domain-specific exception rules.
	Mistake	Action deficiencies	Wrong rules; Inelegant rules are performed even when best rules are availed; Inadvisable (imprudent) rules lead to dangerous risks of accidents.
Knowledge-based	Mistake	Selectivity	Mistakes will occur if attention is given to the wrong features or not given to the right features.
	Slip	Workspace limitations	The conscious workplace has finite resources. The load or cognitive strain imposed upon the workspace varies critically with the form of problem presentation.
	Mistake	Out of sight, out of mind	The operator sometimes gives undue weight to facts that come readily to mind, otherwise ignores facts which are not immediately present
	Mistake	Confirmation bias	A current hypothesis is put apart in the face of contradictory evidence and produces ambiguity that favors one available pre-interpretation.
	Mistake	Overconfidence	The operator will tend to justify his chosen course of action by focusing on evidence that favors it and by disregarding contradictory signs.
	Mistake	Biased reviewing	The check-off illusion. The operator imagined that he checked all different factors, but he didn't.
	Mistake	Illusory correlation	The operator is poor at detecting many types of co variation
	Mistake	Halo effect	The operator has difficult in processing independently two separate orderings of the same people or objects.

	Mistake	Problems of causality	The operator tends to oversimplify causality.
	Mistake	Problems with complexity	Problems with delayed feed-back, lends the operator has a confusion between tasks and facts; Insufficient considerations of process in time, subjects were more interested in the way things are now than in considering how they had developed over previous years; Difficulties with exponential developments Thinking in causal series not causal nets Thematic vagabonding, this involves flitting from issues to issues quickly, treating each one superficially Encysting, this seems to be exact opposite of vagabonding, some topics are treating over and small details, instead other more important are disregarded
	Mistake	Problems of diagnosis	The root of the problem in diagnosis appears to be located in the complex interaction between two logical reasoning tasks

In 1998 Hollnagel (1998) presented a new HRA technique (CREAM) in order to overcome some limitation from previous techniques. The main limitation was binary representation of human actions, and context-dependence actions. Therefore, the method is an attempt to generalize trees of events through a categorization polychotomous to quantify more explicitly the influence of factors on the performance workers. The CREAM taxonomy describes the relationship between causes and manifestations. Causes represent the description of the occurrence of effects and expressions refer to everything what is observed. Regarding the causes, the classification scheme is described in three levels:

1. **Individual:** consists of causes that are associated with personality characteristics, psychological workers;

2. **Technological:** ergonomic factors, and includes everything that represents the state of the components;
3. **Organizational:** consists of causes that characterize the organization, work environment, the interaction between people and environmental conditions.

These three levels can be expanded to represent a more detailed analysis. The CREAM model has two basic principles:

- **Competence:** describes what the worker is able to perform;
- **Control:** describes the ability of the worker in terms of level of control that it has in certain situations.

The CREAM technique has two methods: The Basic CREAM method and the Extended CREAM method. In Basic CREAM, a task analysis is carried out prior to further assessment. Common Performance Conditions (CPCs) are assessed according to the descriptors given in Table 4 to judge their expected effect on performance. However, these assessments are then adjusted according to some specified rules in order to take account of synergistic effects. Finally, a simple count is performed of the number of CPCs which are improving reliability and the number that are reducing it. On the basis of this number, the probable control mode is determine, by determining the region given in Bedford, Bayley and Clare (2008). The Extended CREAM method works slightly differently. Given the task analysis, a cognitive activity is associated to each of the tasks (taken from a standard list which includes activities such as co-ordinate, communicate, compare, etc). This model consists of the Simple Model Cognition (SMoC) and Contextual Control Model (COCOM). The SMoC has these follow fundamental characteristics:

1. Distinguishing between observation and inference, emphasizes the need to distinguish clearly between what can be observed and what can be deduced from observation;
2. Cyclical nature of cognitive action, cognitive functions mean that if both extend to a context of past events and anticipate events future.

Table 4: Common Performance Conditions source: Hollnagel (1998)

CPC name	Level/descriptors	Expected effect on performance reliability
Adequacy of organisation	Very efficient	Improved
	Efficient	Not significant
	inefficient	Reduced
	Deficient	Reduced
Working conditions	Advantageous	Improved
	Compatible	Not significant
	Incompatible	Reduced
Adequacy of MMI and operational support	Supportive	Improved
	Adequate	Not significant
	Tolerable	Not significant
	Inappropriate	Reduced
Availability of procedures/ plans	Appropriate	Improved
	Acceptable	Not significant
	Inappropriate	Reduced
Number of simultaneous goals	Fewer than capacity	Not significant
	Matching current capacity	Not significant
	More than capacity	Reduced
Available time	Adequate	Improved
	Temporarily inadequate	Not significant
	Continuously inadequate	Reduced
Time of day (circadian rhythm)	Day-time (adjusted)	Not significant
	Night-time (unadjusted)	Reduced
Adequacy of training and expertise	Adequate, high experience	Improved
	Adequate, limited experience	Not significant
	Inadequate	Reduced
Crew collaboration quality	Very efficient	Improved
	Efficient	Not significant
	inefficient	Not significant
	Deficient	Reduced

COCOM has four control modes:

1. **Scrambled control:** situation of danger where there is little or no correspondence between the situation and action. The actions are chosen randomly little or no cognitive reflection involved;

2. **Opportunistic control:** choice of inefficient actions, where the worker can master the situation somewhat because of his ability and experience;
3. **Tactical control:** the worker's performance is based on rules, where the same has a reasonable knowledge.
4. **Strategic control:** optimal control, where the worker has the most robust and efficient performance based on his knowledge and his ability.

Through four levels of the COCOM, it is possible to question if the worker maintains or lose control in certain situations and predict the expected level of reliability performance, according to Bedford, Bayley and Clare (2008). The mechanics of the calculation imply that the CPCs play a role in scaling a basic probability up or down. Hence in Extended CREAM, the CPC acts mathematically rather like a Performance Shaping Factor does in other methods, by adjusting a nominal probability. This implies that while CPCs determine the absolute level of failure probability in Basic CREAM (through the determination of the control mode), they determine the relative level of failure probability in Extended CREAM. This is a major difference between the two methods. Another major difference is that within Basic CREAM the underlying task analysis does not appear to play a role in determining the control mode: the control mode only depends on the CPC values. Note that Hollnagel (1998) also describes what might be called a simplified-extended version of the method in which the adjustments to nominal probabilities are determined through the control mode.

It should be made clear that Hollnagel presents the numbers he provides – weights and probabilities – as plausible rather than as definitive. (Indeed, the qualitative classes are provided on the same basis with acknowledgement that other categories would be required to model HRA problems outside the environment that he has worked in.) Hence, our exploration of the consistency of Basic and Extended CREAM contributes to a discussion of what adjustments could be considered.

4. NEW TAXONOMY AND MODEL OF ERROR SEQUENCE PROCESS FOR HUMAN ERROR ASSESSEMENT

This chapter presents a new taxonomy to classify human errors using the concepts proposed by Rasmussen and Reason and the classification of elementary behavior proposed by Berliner. The combination of these concepts builds a new taxonomy that classifies human error of the worker when he/she is performing an intervention (operator/maintenance) in hydroelectric power systems.
Next is presented a model that describes the mental sequence of the error process, when the worker performs without success an intervention on hydroelectric power systems, and the cause of this unsuccessful intervention was characterized as human error.

4.1. The Proposed Taxonomy

The knowledge of error failure mode, according to the taxonomy proposed by Reason (1990), says nothing about the elementary behavior of the worker during the failed action. What action the worker was doing when the error occurred? Was he/she verifying? comparing? locating? It is necessary to add this elementary behavior that caused the human error, in the taxonomy proposed by Reason (1990), to get a deeper level of detail. This knowledge of the elementary behavior is necessary to complete the diagnosis of the human error on hydroelectric power systems.
Berliner (1964) proposed a taxonomy to classify elementary behavior (see Table 5). In this table, Berliner proposes 32 verbs, divided in a set of 4 process, which define the type of task the worker was performing during the intervention on hydroelectric power system.
The proposed taxonomy is presented in Figure 10. It consists on the hybridism of the taxonomies proposed by Rasmussen, Reason and Berliner. Figure 10 shows, in sequential order, all terms necessary to classify a human error, during an intervention (operaton/maintenance) in a hydroeletric power systems.

Table 5: Berliner Taxonomy

COGNITIVE PROCESS		
TASK	ELEMENTARY BEHAVIOR	DEFINITION
To solve problems and to make a decision.	**Calculate**	To solve a problem using math process.
	Chose	To select after considering all options.
	Decide	To get a conclusion based on a disposal information.
	Compare	To examine the characteristics or qualities of two or more objects or concepts, aiming to identify similarities or differences.
To process information.	**Interpolate**	To determine or to estimate intermediate values among two given values.
	Verify	To confirm.
	Remember	To hold information (short term memory) or to recover information (long term memory).
PERCEPTIVE PROCESS		
To look for and to receive information	**Inspect**	To examine carefully, and to see with critical sense.
	Observe	To take conscious visually the presence or state of an object, indication or event
	Read	To examine visually the information presented in symbolic form.
	Monitored	To follow up the process during a period of time.
	Explorer	To examine quickly displays to get a general impression.
	Detected	To take conscious of presence/absence of physical stimulus.
To identify objects, events and actions	**Identify**	To acknowledge the nature or indication of an object, according to its implicit or predetermined characteristics.
	Located	To look for and determine the object's right place.
MOTOR PROCESS		
Simple/ discrete	**Move**	To change the position of an object.
	Hold	To apply a continue pressure over a control.
	Push/Pull	Exert force for far/near the body of agent.
	Give	Placed an object in possession of another person to use it.
	Remove	Highlight and move out of position.
	Discard	To take off an object unusual or unnecessary.
	Give back	To return an object to its owner.
Complex/ continue	**Position**	Operate a control that has states discrete
	Adjust	To operate a continue control.
	Typing	To type on a keyboard.
	Install	Put in place or position indicated
COMUNICATION PROCESS		
	Answer	To answer a requested information.
	Inform	To disclose an information.
	Request	To request information.
	Register	To document something, in written form.
	Order	To order an action.
	Receive	To be an information target.

This taxonomy presents five words, which classify human error committed by a worker. The five words, one in each block, are chosen by the analyst in the blocks of Figure 10, according to RDFH (Relatorio de Desligamento por Falha Humana). The first block is the Berliner Process. One of the four words is chosen according to the task. If the worker needs to solve problems and make a decision or to process information, the analyst chooses cognitive process. If the worker needs to looking for and to receive information or needs to identify objects, events and actions, the analyst chooses perceptive process. If the worker needs to perform motor tasks as move, adjust etc, he/she chooses motor process. If the worker needs to perform communications tasks as answer, request, order etc, he/she chooses communication process**.** The second block is domain. One of the three words is chosen according to the standardization of the task. If the task is unique, it is written step by step, the worker does not choose between several tasks, he/she choose the domais of skill**.** If tasks are written step by step but the worker needs to choose between several similar tasks, he/she chooses the domais of rule**.** If the task is not written, the worker needs to create a specific task for the event, and he/she chooses the domais of knowledge**.** The third block is elementary behavior. Elementary behavior is connected with the Berliner process. Each Berliner process has a set of elementary behaviors. Elementary behavior is a set of 32 verbs that define the action of the worker at the time of execution of the task. The analyst chooses elementary behavior according to the task being performed by the worker and the Berliner process already chosen. The fourth block is failure mode. Failure mode is connected with domain. Each domain has a set of failure modes. The analyst chooses failure mode according to the human error committed. The fifth block is error type. Error type is connected with domain and failure mode. The analyst chooses error type according to domain and failure mode.

The company that was studied in this thesis presents human error events in descriptive reports called RDFH (Human Error Shutdown Report). See Annex 1 to 7 for examples. Next, it will be presented how these reports (RDFH) are prepared. Examples of how to build the proposed taxonomy via the analysis of RDFH will also be presented.

This more comprehensive classification allows the analyst to build a table with the human error description and classifications of a set of occurrences collected in the field about interventions (operaton/maintenance) on the hydroelectric power system that resulted in shutdown (blackout) caused by human error. This new taxonomy does not use Performance Shaping Factors (PSFs). In Menezes & Droguett (2005), an attempt was made for the application of PSFs to the quantification of human error in cases of replacement string insulators in transmission lines, and the difficulties were too great. In hydroelectric power companies, data about the influence of PSFs in human error generally are scarce when mostly non-existent. Additionally, most companies have difficulties to talk about human errors. These give rise the difficulty in building a human error database delivered for all interested in human error research. In order to illustrate as well as analyze the proposed taxonomy, it is useful to get with a real case.

Indeed, by using the proposed taxonomy and data collected (RDFHs) from a Brazilian Hydroelectric Power Company, a table with 131 real cases was built. See Annex 8 and Annex 9. This table with the collected human error, forms a data base that allows to statistically explore the reasons and outcomes of these human errors. This statistical analysis could show possible sources of bias, correlation and allow to look for answers that can point to possible changes of procedures to reduce human error. Applying descriptive statistics to this table (see Annex 9) it is possible to infer recurrent features of human error that can be worked out internally in the organization to minimize the outcome of power electric system interruptions during required interventions.

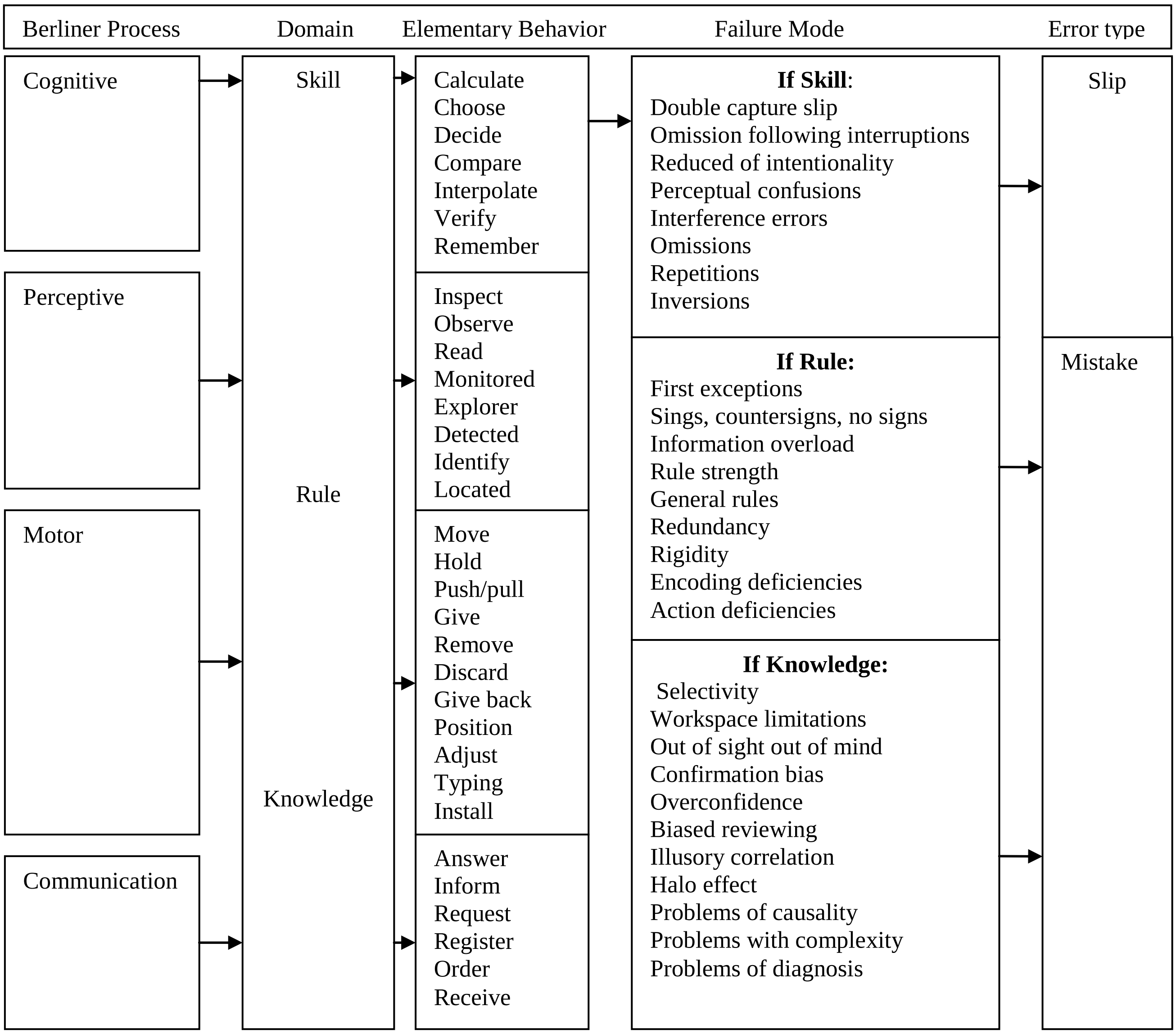


Figure 10: The proposed taxonomy

4.1.1. How human error data were collected

The following describes the data collection in a power hydroelectric company according to the proposed taxonomy. Additionally, examples are presented to show how to apply the taxonomy to real cases. First it is describes how the human error data were collected; how the human error reports (RDFH) were analyzed and how the table Summary of Occurrences, in Annex 9 was built, using the proposed taxonomy.

A Brazilian hydroelectric power company has collected and classified human errors since 1998. The resulting data has been used as a decision index to formulate its non-interrupted system safety policy. Discontinuities in the hydroelectric power system are penalized with fines by the regulatory agency (ANEEL). These fines are of high values and proportional to the time of power system interruption and the interrupted load. In this context, the human error represents an important index about the quality of the energy offered to consumers. These human error reports (RDFH) are recorded in a private data base. From 1998 to 2009, there are 605 available reports relating human errors in hydroelectric power system interventions. Each human error in complex systems such as the hydroelectric power systems must be analyzed so that the error mechanisms are understood. As it is not possible to analyze all available records in a time effective way, it is necessary to choose the main events to apply the proposed taxonomy. Each of the 605 human error reports were analyzed and 474 of them did not cause load interruption as, for example, the load was immediately transferred to other power source or the load did not energize, or it was released for maintenance. These 474 human errors reports were not considered because they do not represent significant losses for the company. On the other hand, the 131 remaining human errors (see Table 6)**,** caused load interruption due to human error. One by one these 131 human errors reports were analyzed in detail and classified according to the proposed taxonomy (See Annexes 8 and 9).

Table 6: Number of Human Errors x Year

YEAR	NUMBER OF HUMAN ERROR	NUMBER OF HUMAN ERROR WITH LOAD INTERRUPTED	LOAD INTERRUPTED DUE HUMAN ERROR (MW)
2009	31	6	1.009,12
2008	27	6	99,26
2007	38	10	386,91
2006	56	11	656,47
2005	49	13	799,63
2004	54	14	947,08
2003	62	12	596,54
2002	57	10	1.572,20
2001	43	11	584,92
2000	75	19	836,90
1999	49	14	740,26
1998	64	5	515,90
Total	605	131	8.745,19

The human error report is elaborated by an expert group. They analyze the undesirable event going *in loco*; interviewing the employees involved; analyzing the power system configuration; analyzing sequences of causes and effects and after that, by writing a report. These reports are written with strong technical language with terminology of electrical engineering and hydroelectrical power systems. This way, it is difficult for an electric power system outsider to be able to analyze these reports. The information is posted on the reports in discursive form without fixed fields to fill, so each report has its own features. As a result, it is difficult to built a database to statistically study the undesirable events.

The company does not use a taxonomy to classify the human error type. This fact makes it difficult to analyze the root causes of the failure event to prevent new undesirable events. Sometimes the specialists use an Ishikawa diagram as in Ishikawa (1993) to find causes about the failure event, but this step is not standardized. Without a taxonomy it is impossible to classify the human errors and find the biases, trends and similarities among events. Another important point is that the company only registers human error, building RDFH, when this error causes shutdown. Human errors that only caused incidents are not registered. Thus important information about the human behavior is lost and a indeep analysis is not possible.

Analyzing the reports recommendations it can be seen that they are mainly of three types: safety engineering solution using devices to block the possible erroneous action, or changes on procedures or electrical configuration to avoid the human erroneous behavior, or enhancing the training program to employees. Each human error report has the follow information about the system configuration:

- An event description: with date, time, place and a summary description of the human error;
- Electrical System configuration;
- Historical occurrence: with the task describes step by step and on chronological sequence;
- Relevant facts and data about the event;
- Task analysis;
- Discursive analysis of the performance of the teams involved;
- Ishikawa diagram;
- Action plan to avoid the repetition of this event;
- Conclusions
- Name and signature of experts responsible for drafting the report.

These reports have enough information to enable an expert on electrical engineering to know the real cause of the human error.

Each of the 131 RDFH was analyzed and based on the proposed taxonomy Annex 9 was built. From the classification built in the last column of the table in Annex 9, the table in Annex 8 was built, which is the basis for the descriptive statistical analysis presented in the next chapter. To illustrate how the analyzes were performed under the new taxonomy, two real cases extracted from "Summary of Occurrences" (see Annexes 8 and 9) are presented.

4.1.2.How to perform the proposed taxonomy

Example 1: The operator shut off the 12J1 circuit breaker instead of the 12J2 circuit breaker in the same panel.

Report error n. 046 April, 20 2001, load interrupted 8,00MW.

Summarized description:

After the team had completed the maintenance, the responsible team (leader) began the process of concluding the intervention (maintenance) and return of equipment to normal operation. The operator on the substation was ordered by the responsible team maintenance to perform maneuvers re-energizing the circuits that were under maintenance. The operator left the substation control building and went to the fenced enclosed area and performed the procedure inspection standards. Then back to building control, the operator initiated the re-energizing of circuits, closing circuit breaker 12J2. The operator has confirmed the closure of the breaker 12J2 observing the corresponding signaling panel. The responsible team (leader) for the maintenance, hearing the noise characteristic of the circuit-breaker closing, signalized for the operator, confirming the close of the circuit breaker. Then the operator went to the panel 12J1, (identical to the neighbor 12J2), made the opening of 12J1, committed an human error (thinking that he is opening 12J2), confirmed the signs on the panel and got a positive sign of the maintainer (which also had moved into the control building), and once again heard the characteristic sound of the circuit breaker opening. The operator recorded the time (16:15 h), signed the card confirming receipt of the breaker, and consulted the program maneuvers normalization of 12J2. At this moment, the operator received a call from CROL (central control) questioning what was going on in the installation, because there was a complaint of COSERN (costumer) about the lack of tension in the city of Tangará. At this moment, the operator became aware that he had opened the wrong circuit breaker.

Using the Proposed Taxonomy

In according to Table 5, the operator used the perceptive process (*to identify objects, events and action),* in order to identify the breaker to shutdown. Then he noticed that the rule was written and mentally he decided to use the skill-based domain to perform the task. When the operator mentally decided to perform the task, he had a perceptual confusion: perform task without paying due attention to what they are doing and committed a slip, and the task was performed without success. Figure 11 presents the taxonomy of these example. This Figure 11 presents five words that classify human error committed by the operator in the example presented. Analysing Figure 11, it is known that a slip was committed, due to a perceptual confusion, that is a failure concentration of identify the correct circuit breaker should be open. As this maneuver is routine, there was a written rule to be followed by the operator, so he was in the domain of skill. The operator performed the rule correctly, however he wrongly identified the circuit breaker. Since the elementary behavior of the operator was "identify", he mentally chose the perceptive process to perform the task.

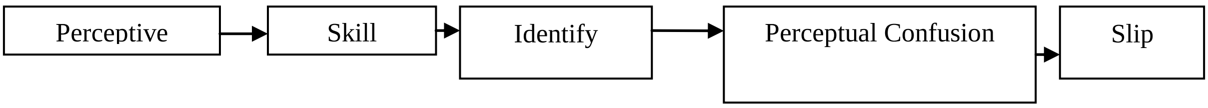


Figure 11: Taxonomy for example 1

Example 2: the maintenance technician did not make correct rely adjust. When the operator push the breaker bottom, occurred the interruption.

Report error n. 012 March, 03 1999, load interrupted 11,00MW.

Summarized description:

It was observed that the reason for automatic shutdown of the transmission line LT 02V6 was the relay operation of low frequency. The underfrequency relay is calibrated to shutdown LT when the frequency drops to a specified value during a certain time interval. This is to protected them. Later inspection in the relay that disconnect the LT showed that the technical of maintenance acted improperly adjusting the relay to operate in 5.0 seconds when the rule recommended this relay set to operate in 11.0 seconds. The technical of maintenance also observed that the relay was defective, not accepting adjustments in excess of 10.0 s. This incorrect adjustment was made nearly three years before the shutdown of LT.

Using the Proposed Taxonomy

The worker used the Perceptive process (to identify objects, events and action) to identify the relay to adjust. Then he perceived that the rule was written and mentally he decided to use the rule-based domain to perform the task. When the operator mentally decided to perform the task, he had a encoding deficiencies (certain properties of the problem space are not encoded at all) and committed a mistake and the task was performed without success. Figure 12 presents the taxonomy of this example. This Figure 12 presents five words that classify human error committed by the technical of maintenance in the example presented. Analysing Figure 12, it is known that a mistake was committed, due to a encoding deficiencies, that is a failure observation of inspect the correct adjust of the relay. As this task is routine, there was a written rule to be followed by the technical of maintenance. The operator chose the incorrect rule. He was under the domain of rule. Since the elementary behavior of the technical of maintenance was "inspect", he mentally chose the perceptive process to perform the task.

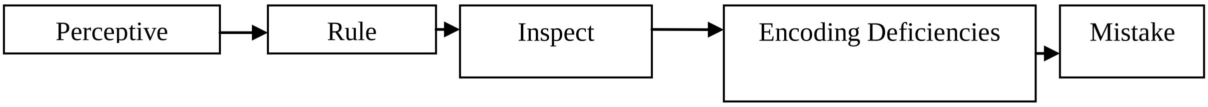


Figure 12: Taxonomy for example 2

4.2. Model of Error Sequence Process

As seen in Annex 8 and Annex 9, the proposed taxonomy satisfactorily translates the information in the RDFHs. However, only the taxonomy is not sufficient to show the sequence of mental events and the relations of cause and effect that can lead a worker to commit human errors in the operation and maintenance of power hydroelectric systems. The model proposed here is based on the taxonomy discussed in Section 4.1, and shows the sequence of mental choices and the relations of cause and effect between the five words chosen by the analyst, which are made by the worker from the moment he becomes aware of the task that he will have to perform. This sequence of choices may lead the worker to perform the task successfully or a human error.

Figure 13 shows the proposed model of the sequence of mental choices which the worker performs.

Figure 13: Error sequence process

The first step is when the worker becomes aware of the task he ought to perform. Mentally he chooses one of the 4 Berliner Processes: Cognitive; Perceptive; Motor or Communication. Cognitive is when the worker needs to solve problems and to make a decision or to process information. Perceptive is when the worker needs to look for and to receive information or to identify objects, events and actions. The Motor process is when the worker needs to move, hold, push/pull, give, remove, discard, give back, position, adjust, type or install. Communication is when the worker needs answer, inform, request, register, order or receive. Then, the worker mentally decides what domain he chooses to perform the task. For this the worker has to mentally follow the flow diagram shown in Figure 14. In sequence, worker mentally decides what elementary behavior he will use to perform the task. Elementary behavior is an internal decision of the worker and is linked to the Berliner process already decided by the worker. If the worker chooses a wrong or inadequate elementary behavior, the task will probably not be performed and usually the worker corrects the choice and starts again the process. According to the diagram shown in Figure 14**,** if the rule was correctly written or it was correctly created and the worker performed the rule correctly, the task will be performed with success. If not, a latent failure or three types of error could be committed:

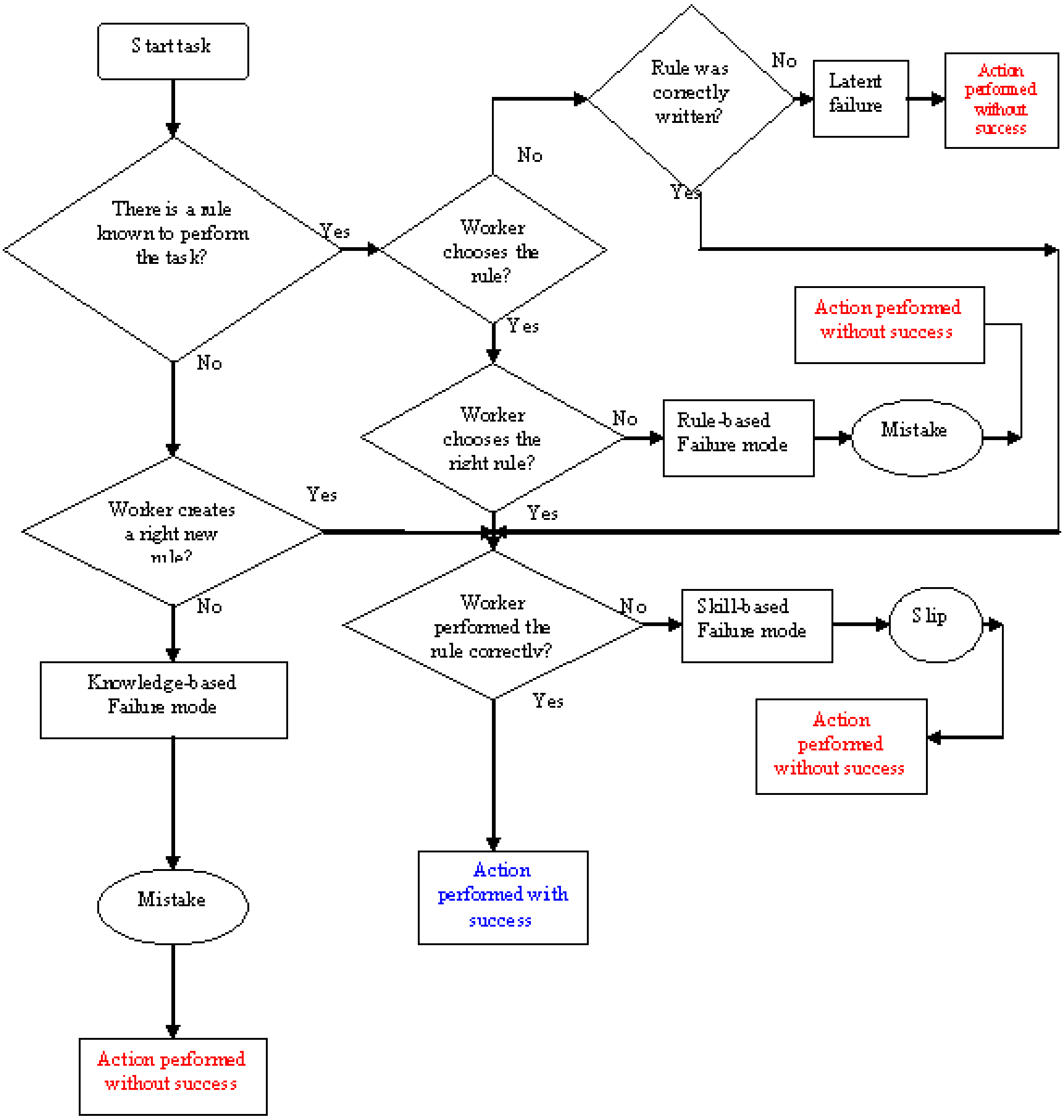


Figure 14: The paths of human error

1. **Latent failure**: There was a written rule, worker does not choose a rule, worker performed the rule correctly but the rule was written incorrectly;
2. **Skill-based slip**: there was a written rule, worker does not choose a rule, rule was correctly written, worker performed the rule incorrectly duded a failure mode;
3. **Rule-based mistake**: there was a written rule, worker chooses a rule, worker chooses incorrect rule;
4. **Knowledge-based mistake:** there was not a written rule, worker creates a new rule, and this new rule is a wrong rule.

It is important to note that this entire model is totally mental, i.e. it starts and ends in the worker's mind. The materializing of error that produces an undesirable event happens after the worker has decided to commit the error mentally, but the consequence of these decision

remains undesirable. The failure mode causes a confusion of mind, which decouples the decision to take the wrong action of consequence of error, causing an undesirable consequence. Both error type, slip and the mistake, are caused by failure modes at the time the worker will perform the task. The probability of a given failure mode occurrence for a given task within this model of sequence error is quantified using Bayesian networks in Chapter 6.
To illustrate these concepts and clarify the model, the next section presents some examples taken from real cases.

4.2.1.How to perform the proposed model

Example 1

Report error n. 046 April, 20 2001, load interrupted 8,00MW.

Summarized description: The operator of the substation following the general program of maneuvers made improper shutdown of circuit breaker 12J1when he had to turn off breaker 12J2 which is positioned near 12J1 on the same electric panel.

The detailed analysis of this event revels that:

1. The operator was conducting a program of maneuvers previously elaborated by a team of engineers;
2. This program about appropriate step asks the operator to shutdown breaker12J2;
3. Shutdown of a circuit breaker is a step of the maneuver program;
4. Shutdown of a circuit breaker is a maneuver that the operator knows how to make, and has made many times during his professional life;
5. The operator read the step which he has to shutdown breaker12J2;
6. The operator perceived that he had to go to the appropriated electric panel and he did it;
7. The operator looked the electric panel, and saw breaker12J2;
8. The operator decided to shutdown breaker12J2;
9. The operator had a perceptual confusion and positioned his hand in front of breaker; 12J1
10. The operator shutdown breaker 12J1 committing a slip.

Comments:

- The operator had a perceptual confusion reading incorrectly the maneuver program and/or simply confounding the codification or positioning of the breaker on the electric panel;

- The codification is 12J1 and 12J2 so that it is easy to make confusion;
- 12J1 is positioned next to 12J2 on the electric panel;
- The maneuver program was correct;
- The rule to shutdown breakers was correct, and the operator choose the correct rule;

Sequence of error process:

Figure 15 shows sequence of error process for example 1.

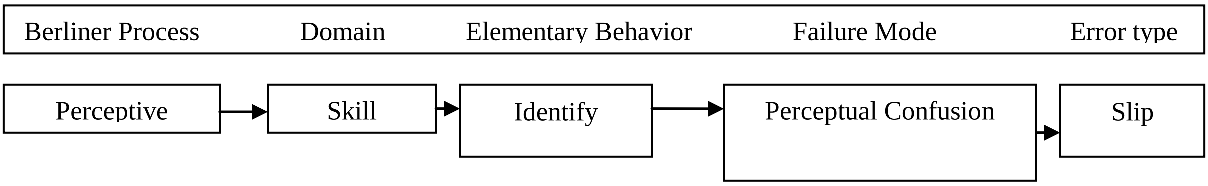


Figure 15: Sequence of error process for example 1

The operator used the Perceptive process (to identify objects, events and action) to identify the breaker to shutdown, then he perceived that the rule was written and mentally he decided to use the Skill-based domain to perform the task. When the operator decided to perform the task, he had a perceptual confusion (perform task without paying due attention to what they are doing) and committed a slip and the task was performed without success. Figure 15 shows the taxonomy and model to example 1.

Example 2

Report error n. 007 May, 26 1999, load interrupted 9,54MW.

Summarized description: The responsible for the intervention detected a fault in the supervision circuit: “abnormality of breaker and disconnector”. Then in order to correct the problem, he pressed the relay 62X of the protective chain of LT04L1, causing the abnormality.

The detailed analysis of this event revels that:

1. The worker was conducting a program of maintenance previously elaborated by a team of engineers;
2. The worker detected an abnormality in the supervisor circuit;
3. This abnormality was not part of the maintenance program;

4. The worker decided to correct the abnormality;
5. The worker based on his experience and for rule strength, chose a rule to correct the abnormality;
6. The worker chose a wrong rule committing a mistake.

Comments:

- The worker trusting in his expertise, used a rule that he figured that was the correct rule to correct the abnormality.
- The rule chosen by the worker was not part of the maintenance program;
- The worker knew all rules to perform the task

Sequence of error process:

Figure 16 shows sequence of error process for example 2.

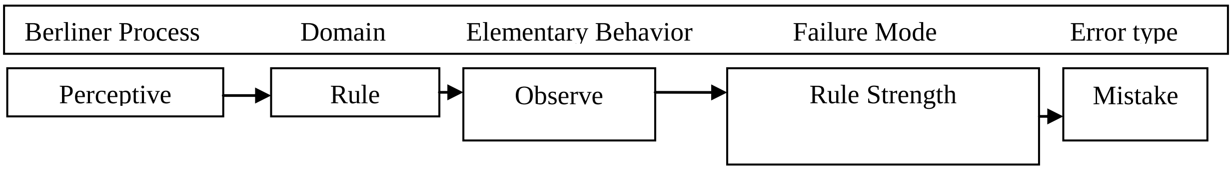


Figure 16: Sequence of error process for example 2

The worker used the Perceptive process that is: *to* look for and to receive information, to observe an abnormality on supervision circuit, then he knew that there was a written rule that he mentally decided to use the Rule-based domain to perform the task. When the operator decided to use a rule already known to perform the task, he was victim of the failure mode named rule strength that is: a rule became a strong rule, and the worker can trigger this rule when some but not all conditions are satisfied and committed a mistake and the task was performed without success. Figure 16 shows the taxonomy and model for example 2.

Example 3

Report error n. 035 July, 28 2000, load interrupted 52MW.

Summarized description: The lack of procedure of the mechanical maintenance and poor identification terminals led the mechanic maintenance worker to wrongly connect hoses for interconnection between the pumping unit and fixed pipes, generating a non-compliance which was not detected by subsequent inspection of the operation, keeping the abnormality that caused the shutdown of the generating unit.

The detailed analysis of this event revels that:

1. The worker was not conducting a program of maintenance previously elaborated by a team of engineers;
2. The worker had a mission to make a maintenance;
3. The worker was a very experienced employee;
4. The worker did not consider the deficiency of terminals identification and worked under ambiguity;

Comments:

- The worker did not know a specific rule so, he improvised a rule to make the maintenance of the unit;
- The rule chosen by the worker was not part of the maintenance program;

Sequence of error process:

Figure 17 shows sequence of error process for example 3.

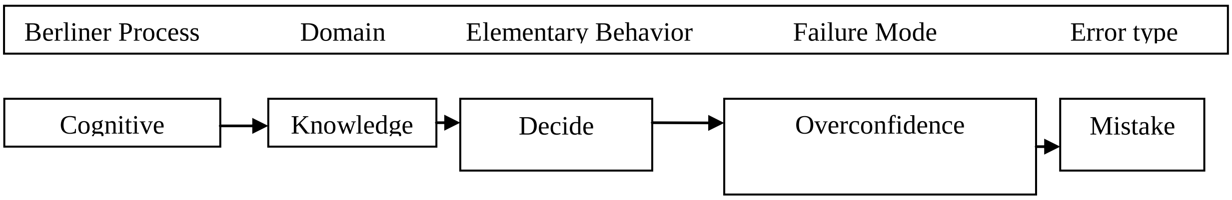


Figure 17: Sequence of error process for example 3

The worker used the Cognitive process that is: *to solve problems and to make a decision*, decided make maintenance, then he knew that there was not a written rule he mentally decided to use the Knowledge-based domain to create a new improvising rule to perform the task. When the operator decided to create a new rule to perform the task, he was a victim of the failure mode named overconfidence that is: the worker tends to justify his choice of action by focusing on evidence that favors it and by disregarding contradictory signs, and committed a mistake and the task was performed without success. Figure 17 shows the taxonomy and model to example 3.

Example 4

Report error n. 004 September, 08 1998, load interrupted 70MW.

Summarized description: After a complete shutdown of the substation, caused by an explosion of the 11E2 breaker, the operator incorrectly performed the sequence of maneuvers.

The detailed analysis of this event revels that:

1. The substation after the explosion was completely shutdown;
2. The operator had to re-energize the substation immediately in the shortest possible time;
3. There is a specific rule to re-energize the substation;
4. The operator knew the specific rule to re-energize the substation, he was trained for that;

Comments:

- When a substation is completely shutdown, the work climate is hard;
- The pressure to immediately re-energize the substation is high;
- The sequence of re-energization is not easy and has many steps

Sequence of error process:

Figure 18 shows sequence of error process for example 4.

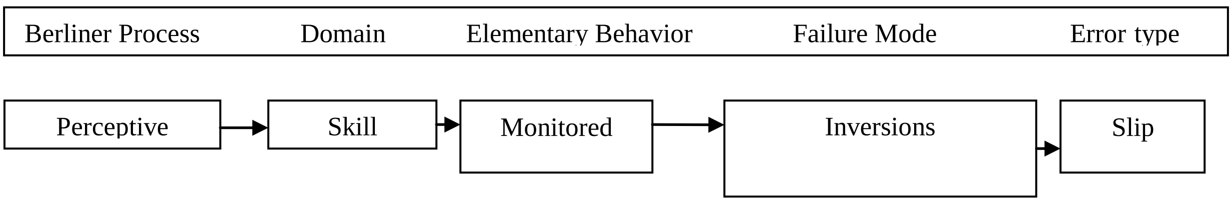


Figure 18: Sequence of error process for example 4

The operator used the Perceptive process that is: *to looking for and to receive information*, to monitor the process of restoring power of the substation. He perceived that the rule was written and mentally decided to use the Skill-based domain to perform the task. When the operator decided to perform the task, he committed a failure mode named inversions that is: the original sequence of the task is reversed, and committed a slip and the task was performed without success. Figure 18 shows the taxonomy and model to example 4.

For more examples see Annex 9. Using this model it is possible to analyze the human error in hydroelectric power systems. Of course, a team of experts to analyze shutdown events and build the diagrams of sequence of error process is necessary. By building a data bank with events, it is possible to understand the nature of human error on a specific company using descriptive statistics as is described in Chapter 5, and using Bayesian networks it is possible to know what failure modes are more probable for a given task, given a particular error sequence occurs (as will be seen in Chapter 6).

5. DESCRIPTIVE STATISTICS USING THE NEW TAXONOMY

This chapter presents a statistic analysis of data collected from a Brazilian hydroelectric power company. Data collected through the RDFH reports were classified according to the proposed taxonomy and organized following the model of the sequence of error as presented in Chapter 4. See Annex 8 and Annex 9. The statistical information was generated by a free software named R™ (GNU project), and is presented through tables and graphs with comments and examples showing trends, frequency, seasonality and contingencies.

In this chapter it was made use of a statistical software named R™ to provide a statistical analysis of the data from the table put together from the human error reports collected and organized following the proposed taxonomy and model of sequence of error.

It was designed an Excel™ table using the data from the reports of human error collected from a Brazilian power electric company. This table, see annex 9, has the follow fields: day, month and year that a human error happened; time in minutes between the start of interruption because of a human error and the recovery system; interrupted load in MW; error domain; type of error; failure mode; Berliner process and elementary behavior.

Number of human errors

The following information in the form of tables and graphs were generated: frequency of elementary behavior; frequency error type; frequency of Berliner process; frequency of failure process; frequency of error domain; human error seasonality; domain annual seasonality; error type annual seasonality; contingencies between failure mode and Berliner process and contingencies between failure mode and elementary behavior.

From 1998 to 2009, the company registered 605 human errors, an average of 50.42 human errors per year. The year of 2000 was the worse and had 75 human errors, whereas 2008 with 27 human errors was the best year. Figure 19 shows the number of human errors from 1998 to 2009. Analysing Figure 19, it is clear that the number of human errors during this period is decreasing.

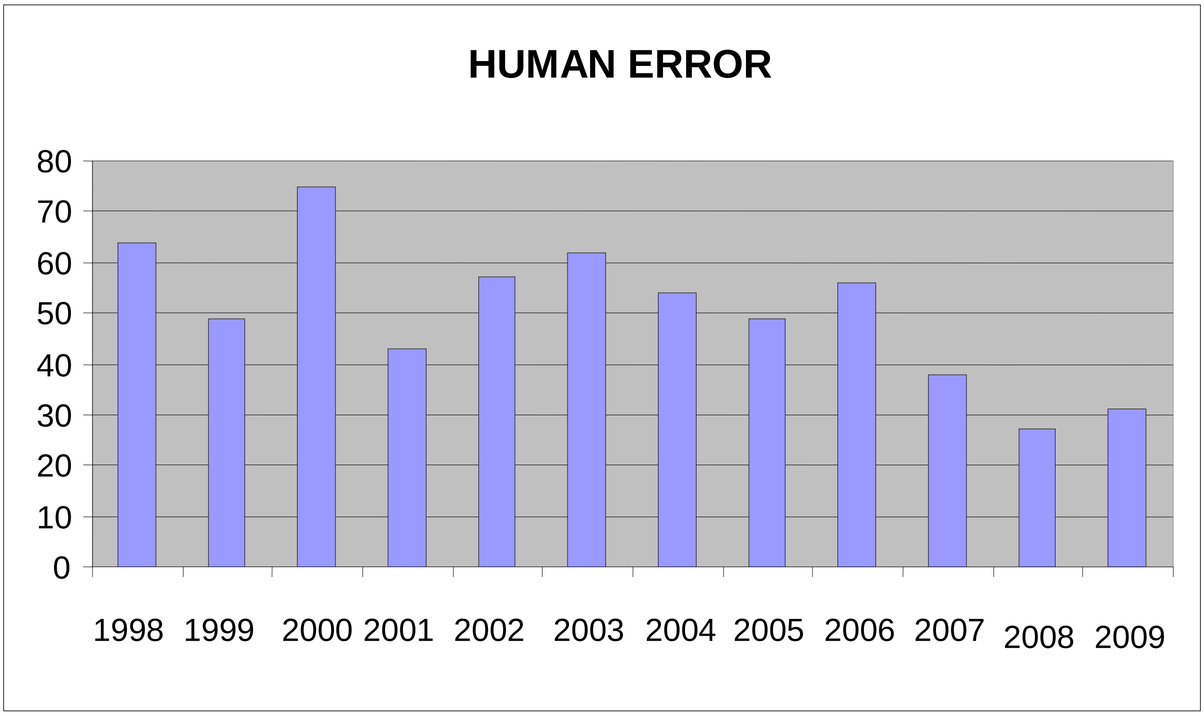


Figure 19 – Human Errors

Most human errors do not cause on important outcome, but some of them cause operational discontinuity. These errors include interruptions output load and lost the electrical energy to costumers. This fact is quite serious because the company image and financial resources are involved. From the collected data, 131 of 605 human errors caused load interruptions in the amount of 8,745.19MW. Only the 131 human error events with load interrupted were considered. Figure 20 shows the some trend of Figure 19**,** i.e.: reduction of the number of human errors per year.

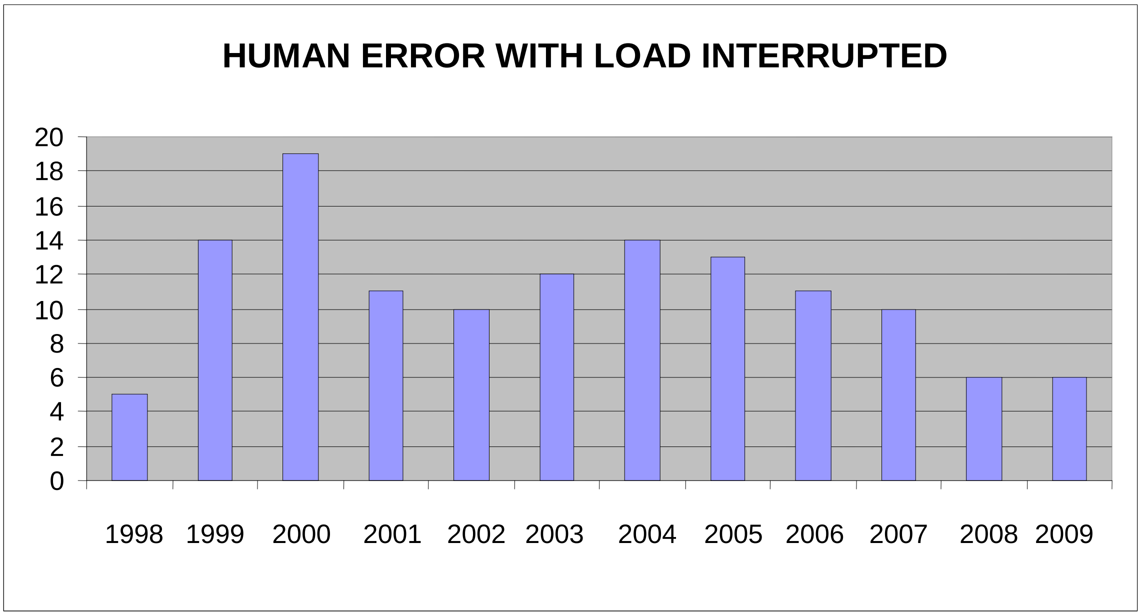


Figure 20 – Human Error with Load Interrupted

Seasonality of human errors

Other interesting information is about the seasonality of human error. Figure 21 shows that there are more human errors on the second semester than on the first one, because the workload is concentrated on the second semester to get done the work program. January and February are holiday months so that the activities are reduced and after the carnival holidays, it is observed a peak of human error. Therefore, it is very important to consider seasonality when elaborating of a human error prevention program.

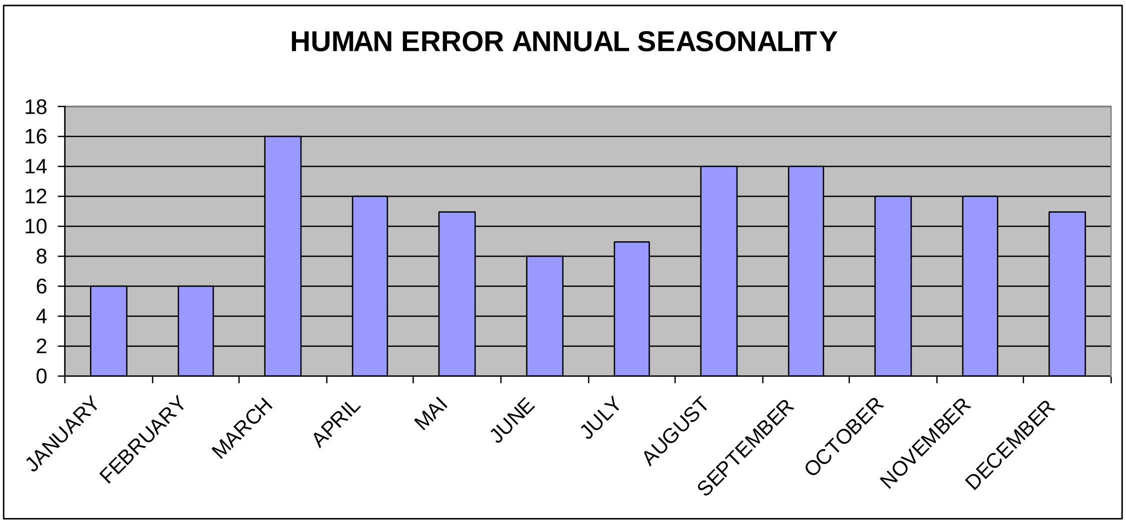


Figure 21 – Human Error Annual Seasonality

In Figure 22, the elementary behaviors “compare” and “identify”, emerge as more frequent than the others, but due to the quantities of elementary behavior, it is not easy to see seasonality issues.

Figure 23 shows the number of human errors month by month during the analysed period. From this graph, it is impossible to see any kind of seasonality. Figure 23 reveals that the error type lapse, (a type of slip when the memory failed), occurs less frequently than the others, ("mistake" and "slip"). It is worth noting another thing: mistakes are predominant on January and February and the slips on November and December.

Figure 24 presents month by month the domains of human error: Knowledge, Rule and Skill. Although seasonality is not perceptived on this graph, it is possible to observe that the skill domain is more frequent on this period.

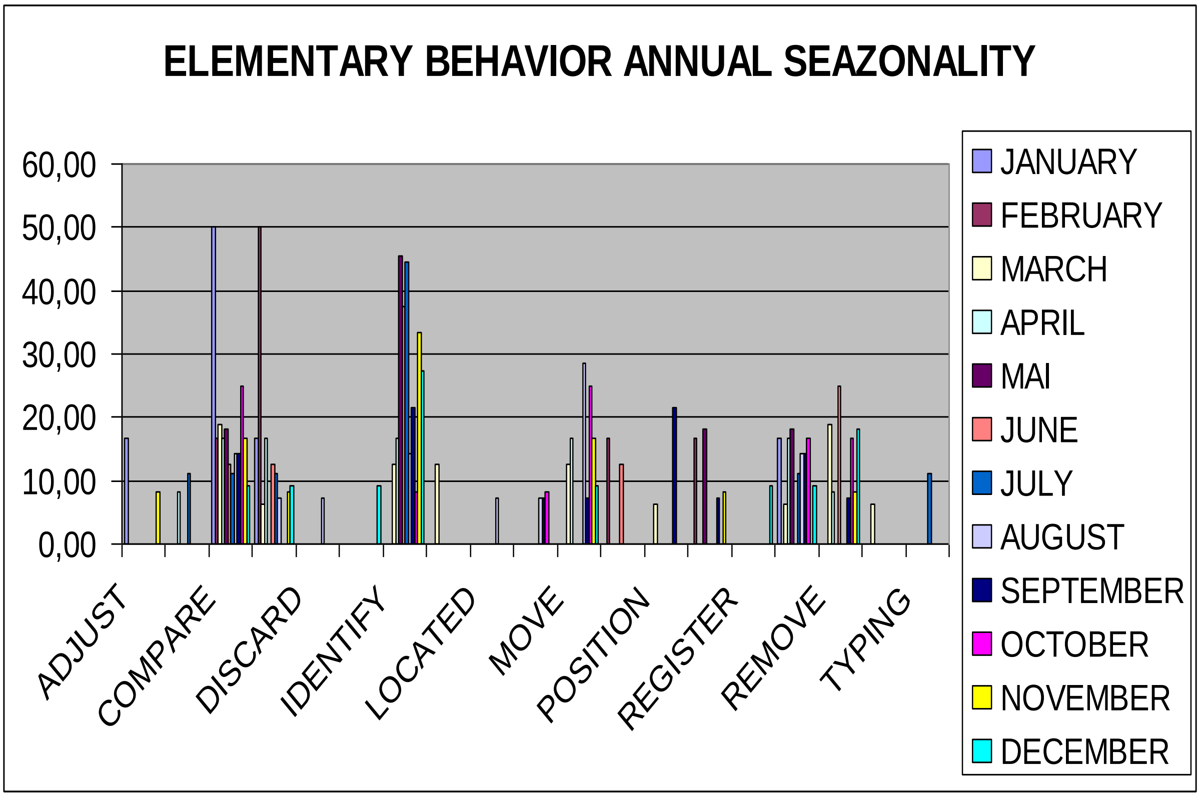


Figure 22 – Elementary Behavior Annual Seasonality

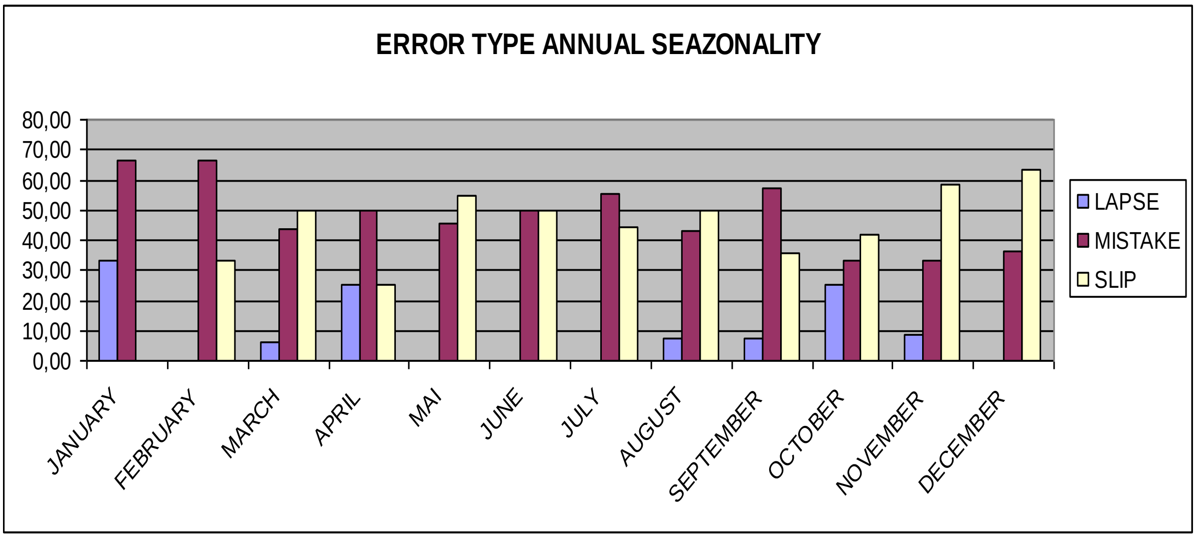


Figure 23 – Error Type Annual Seasonality

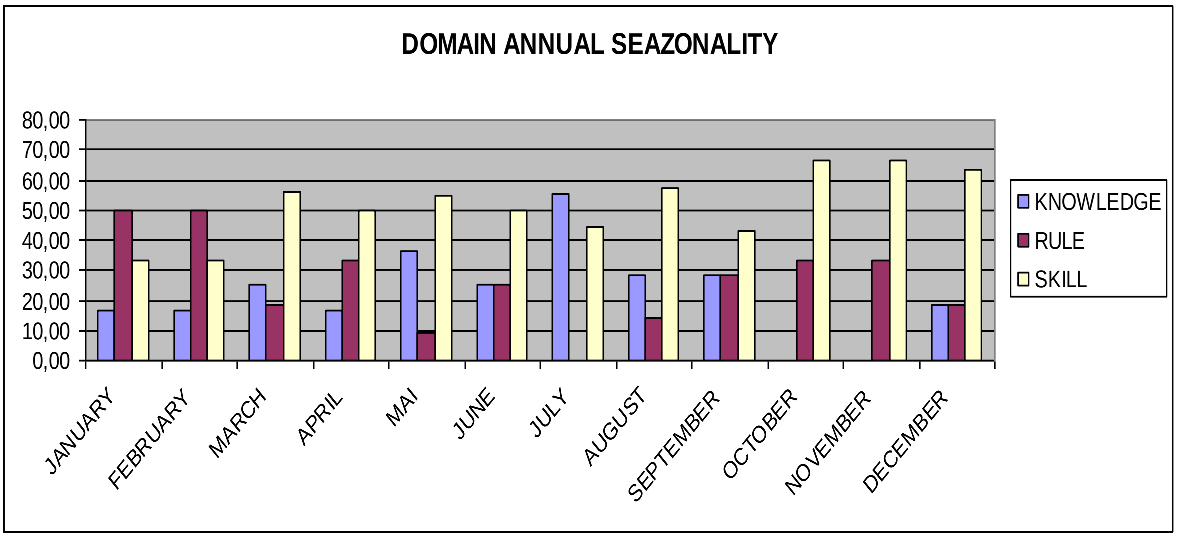


Figure 24 – Domain Annual Seasonality

Frequency of human errors

Figure 25 shows the frequency of human error considering the domains: skill-based; rule-based and knowledge-based.

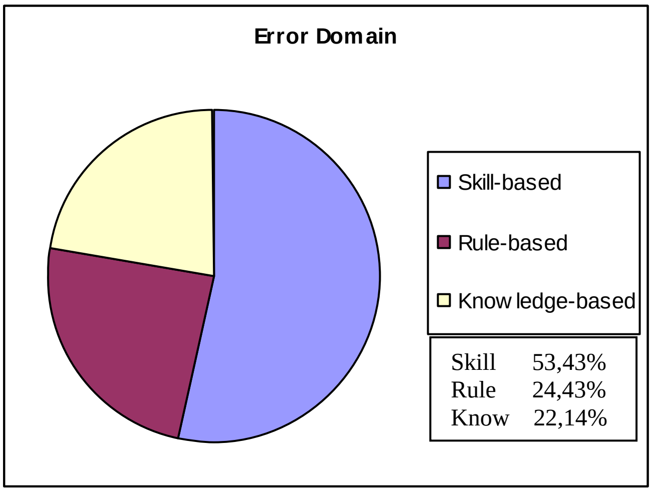


Figure 25 – Error Domain

Figure 25 shows that the domain of skill-based is predominant and the domain of rule-based and knowledge-based are equally distributed. The reason for that is probably because the nature of electrical job as this needs a good hand skill to work in electrical racks on command house, power substation patio and power transmissions lines.

On the other hand, on the frequency of error type, Figure 26 shows that mistakes and slips are almost equally distributed. The mistake type or error is linked with the plan to execute the task. This error is associated with the bad formulation of the plan to execute the task. The slip error is when the action is correctly planned but something happened and the actions do not go as planned. It is necessary to make a study to separate operational errors and maintenance errors to understand where the mistake and/or slip are predominant.

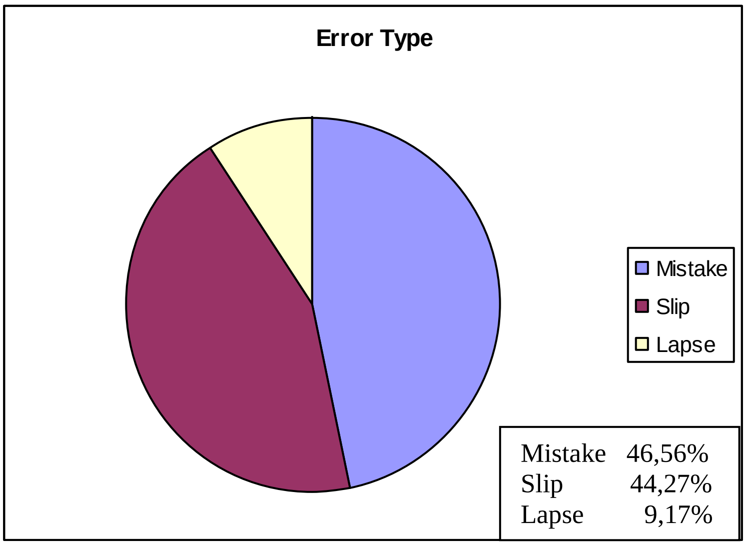


Figure 26 – Error Type

The Berliner processes are: cognitive, motor, perceptive and communication. Figure 27 and 28 show the error on Berliner process frequencies and the frequency of elementary behavior. Clearly the communication process is good and almost free of error, but the cognitive process has the higher frequency. Motor and perceptive processes have almost the same frequency. The cognitive process is to solve problems and to make a decision or to process information like: calculate, choose, decide, compare, interpolate, verify and remember. Compare, remember and decide are the elementary behaviors linked to the cognitive process, which has the higher frequency. Compare and identify are interlinked and are processes to find similarities and differences between two or more objects or concepts. Remember is about deficiencies to hold information on memory.

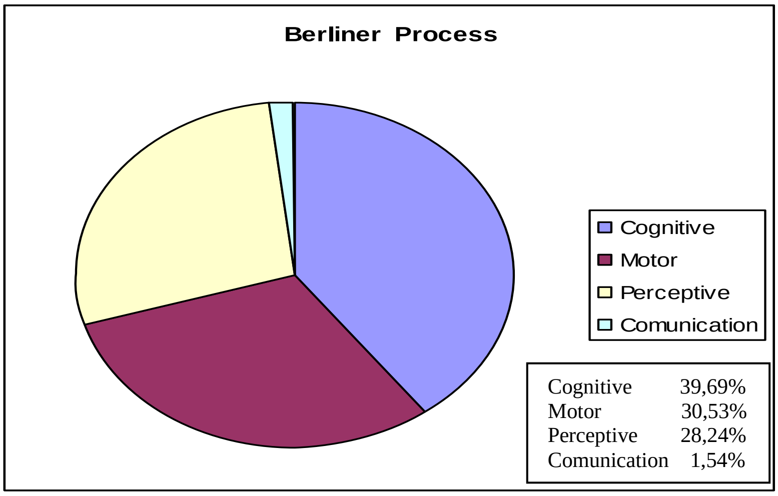


Figure 27 – Berliner Process

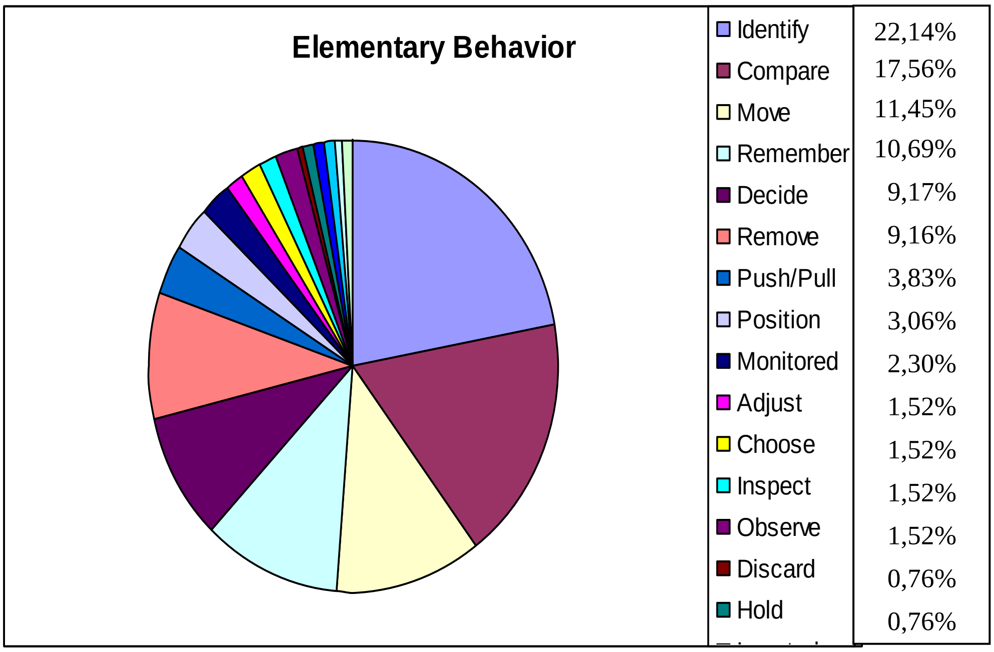


Figure 28 – Elementary Behavior

Figure 29 is about frequency of failure modes. 74% of errors are related to failure mode of: Perceptual confusions, biased reviewing, encoding deficiencies and omission. Perceptual confusion is clearly the higher frequency mode of failure, 42.75%. This mode of failure is when the operator performs tasks without paying due attention to what is being done. Attention is the key word.

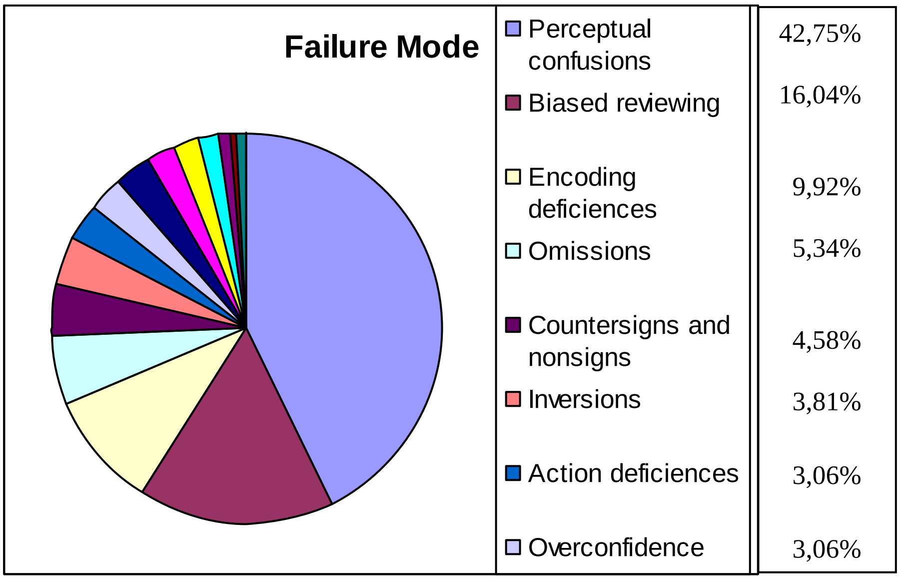


Figure 29 – Failure Mode

Contingencies

Here the relations between different variables will be observed, searching for similarities among them. The following relations will be analyzed: each "failure mode" and "elementary behavior"; each "failure mode" and "Berliner process"; each "error type" and "elementary behavior"; each "error type" and "Berliner process"; each "error domain" and "elementary behavior"; each "error domain" and "Berliner process". This information compares sometimes relations that do not have similarity or there's no observable relation between them, or there is no significative relations between them. However, in many cases, there is an important and significant relation among them. When this relation is significant, it could have important information to understand the error mechanism. Here, it all possibilities among all variables were analyzed (see Annex 9).

The first relation is between failure mode x elementary behavior.

Failure mode x elementary behavior

According to Reason (1990), the failure modes are (See Table 3): action deficiencies; confirmation bias; countersigns and nonsigns; encoding deficiencies; first exceptions; general rules; information overload; inversions; omission; omission following interruptions; overconfidence; perceptual confusions; rigidity and rule strength. According to Berliner (1964), the elementary behaviors are (see Table 5): adjust; choose; compare; decide; discard;

hold; identify; inspect; located; monitored; move; observe; position; push-pull; register; remember; remove; request and typing. The relation among these variables is analyzed below.
Figure 30 shows the relationship between action deficiencies and elementary behavior. Action deficiencies is when the operator, during the execution of the task, performs wrong rules even though best rules are available, and a mistake is committed. Inadvisable (imprudent/wrong rule) rules leads relevant risks of accidents. It is clear that during the observed period, action deficiencies did happen when the operator was deciding or inspecting or moving or observing.

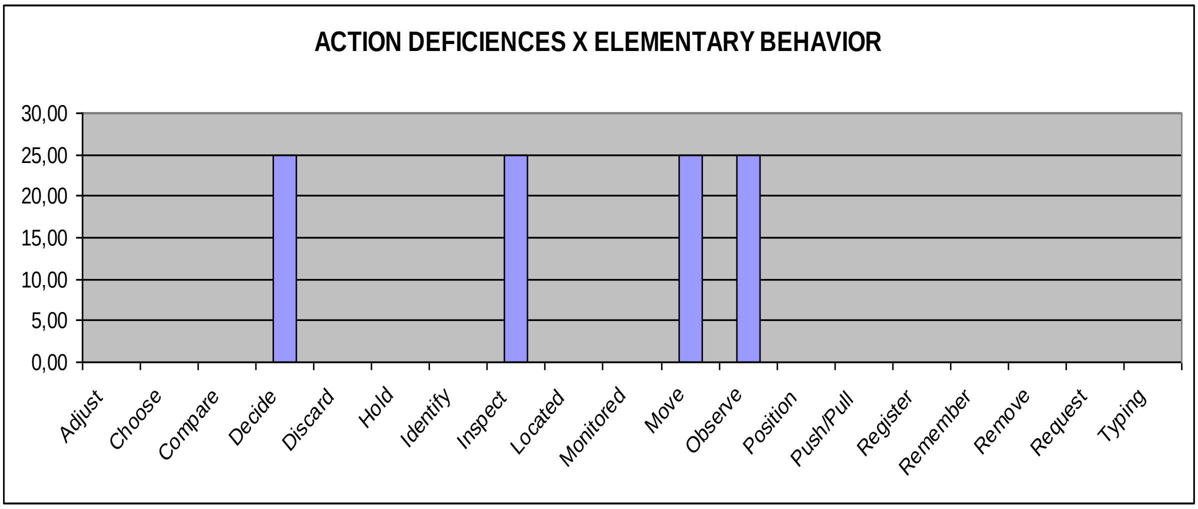


Figure 30 – Action deficiencies x Elementary Behavior

Figure 31 shows the relation between biased reviewing and elementary behavior. Biased reviewing is the check-off illusion, i e: when the operator imagined that he checked all different factors, but he did not, and a mistake is committed. Analyzing the graph, it is clear that during the elementary behavior of compare, the operator does not use to check all factors that could affect his/her performance.

Figure 32 shows the relationship between confirmation bias and elementary behavior. Confirmation bias is when the operators put apart a current hypothesis in face of contradictory evidence and produce ambiguity that favors one available pre-interpretation. This behavior leads to a mistake. Remember that it is the elementary behavior that was observed during the studied period. When the operator has problems with memory, it is usual contradictory evidence that leads to ambiguity and the understanding about performing the rule is damaged, and favors other wrong interpretations.

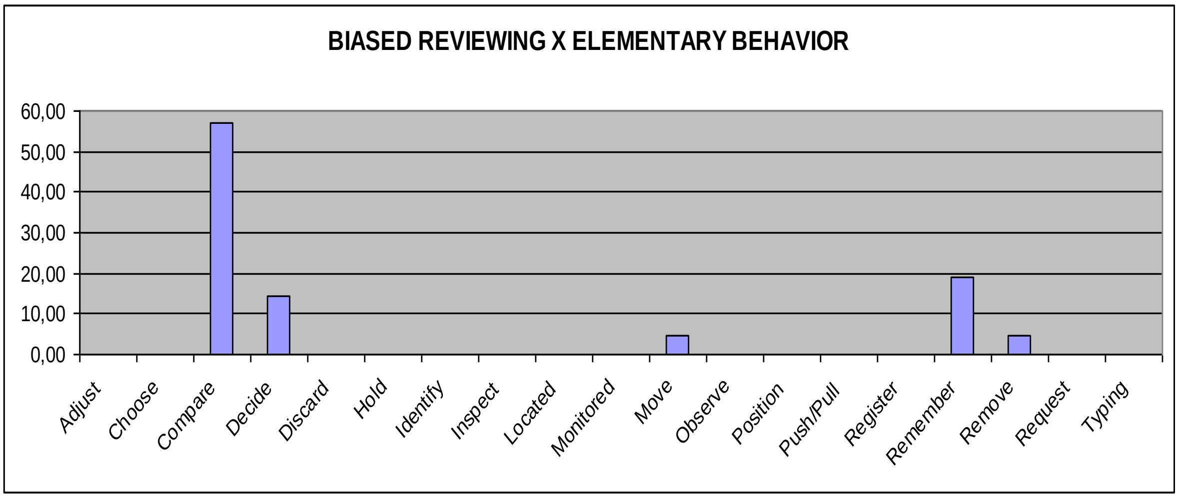


Figure 31 – Biased reviewing x Elementary Behavior

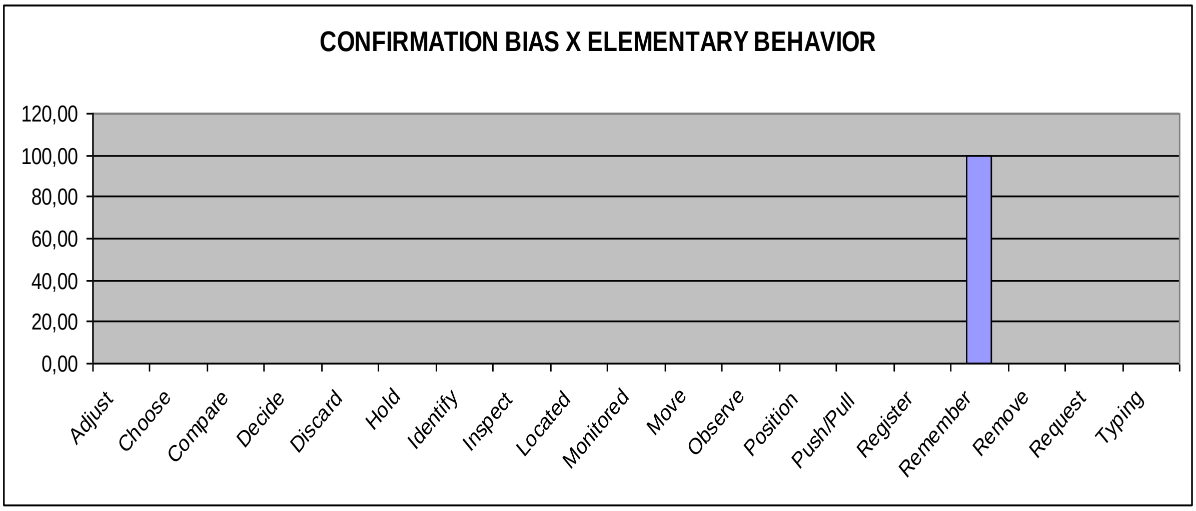


Figure 32 – Confirmation Bias x Elementary Behavior

Figure 33 shows the relation between signs, countersigns, non signs and elementary behavior. Countersign and non sign is when the operator is faced with an ambiguous situation, as the presence of correct signals to trigger a given action, as also countersigns, to not trigger and also to the lack of signs, sometimes simultaneously, which leads to error. This situation occurred during the elementary behavior: compare, identify located, register and remove.

Figure 34 shows the relations between encoding deficiencies and elementary behavior. Encoding deficiencies is when the operator does not encode at all or encodes inaccurately certain properties of the problem space or an erroneous general rule may be protected by the existence of domain-specific exception rules. The elementary behavior of compare was observed in the sample collected.

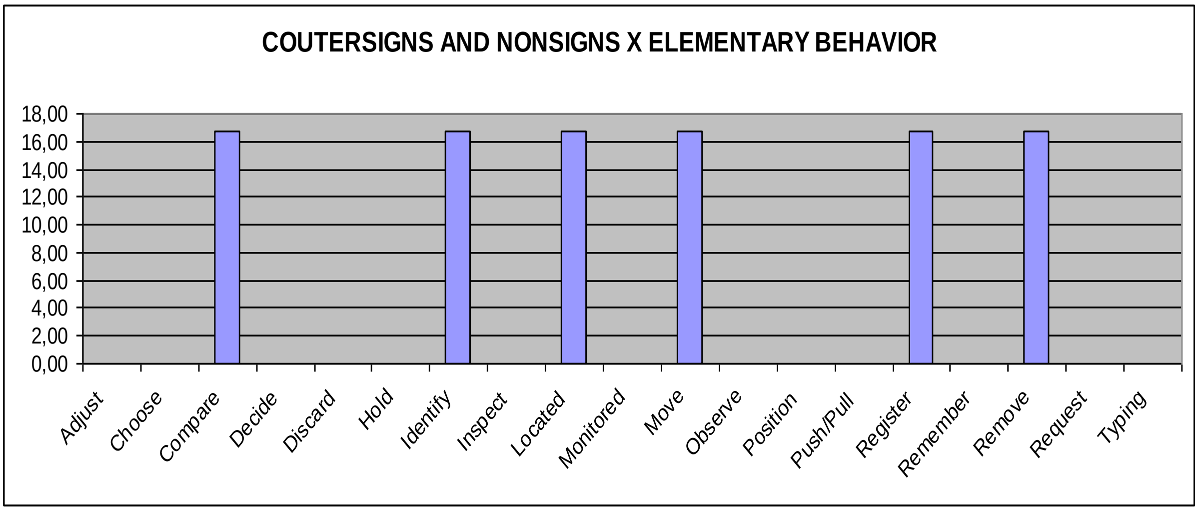


Figure 33 – Sings, countersigns and non signs x elementary behavior

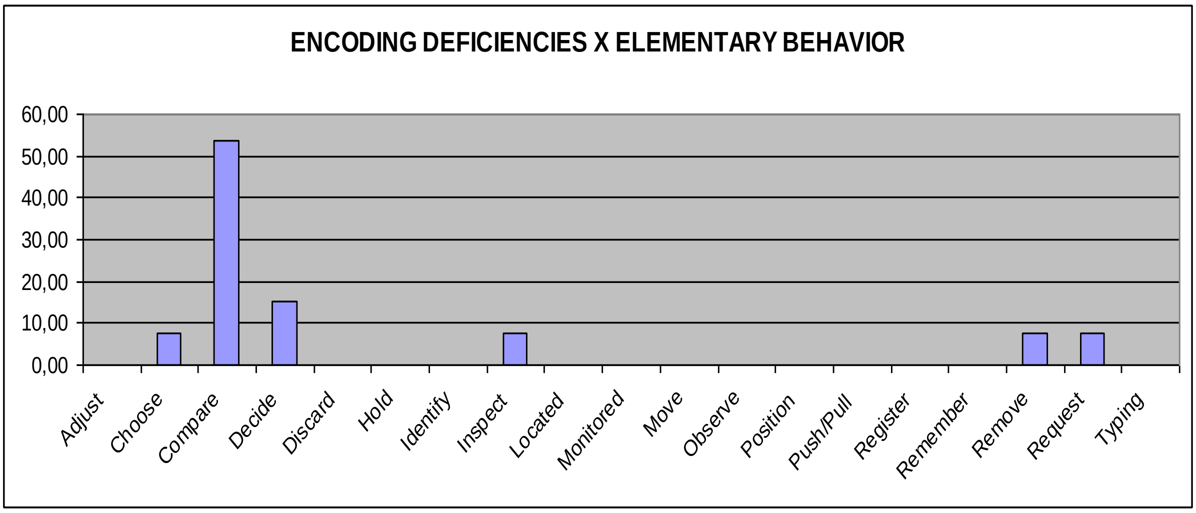


Figure 34 – Encoding Deficiencies x Elementary Behavior

Figure 35 shows the relation between first exceptions and elementary behavior. First exceptions are when the operator is faced for the first time with an exception to the general rule that he/she had always used, and as the general rule has been applied successfully in the past, he/she tends to apply it to the exceptional situation. Thus leading to error. Only the elementary behavior: position was observed on failure mode: first exceptions, during the period studied.

Figure 36 shows the relations between general rule and elementary behavior. The operator wrongly choices a general rule because it is likely to be stronger than an error is committed.

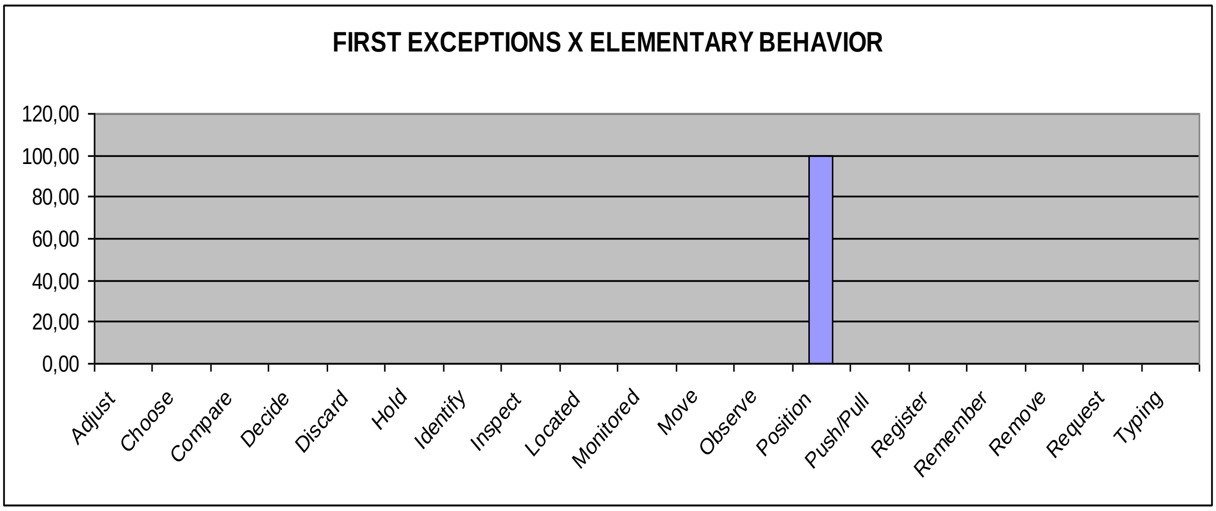


Figure 35 – First exceptions x Elementary Behavior

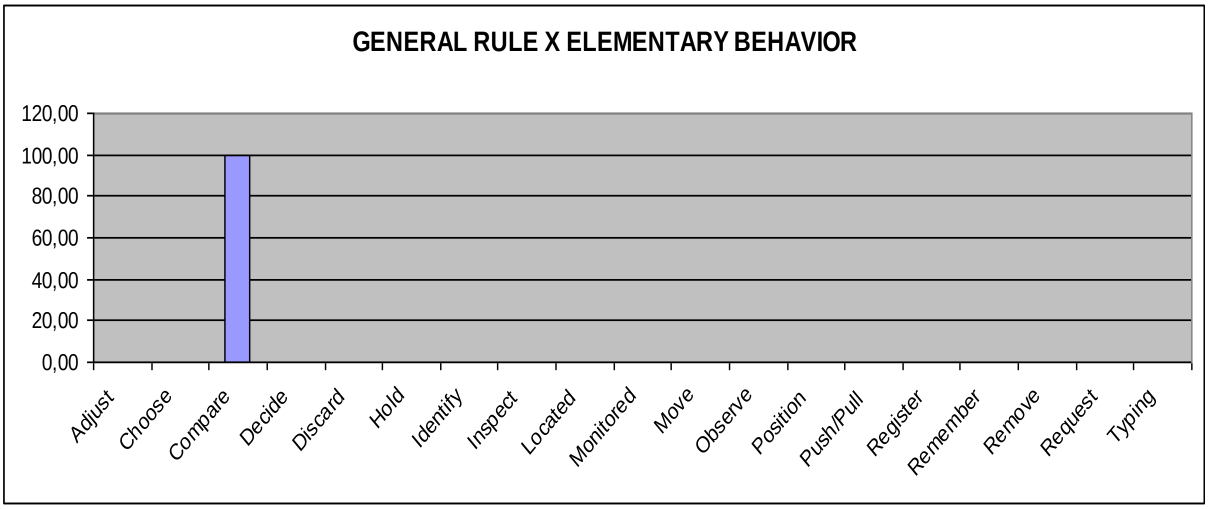


Figure 36 – General Rule x Elementary Behavior

Figure 37 shows the relation between information overload and elementary behavior. Information overload is when there is abundance of information, sometimes undesired, because the local state indication almost invariably exceeds the operator cognitive system's ability to apprehend them, which can lead to error. Position and decide are the elementary behavior observed in this case.

Figure 38 shows the relation between the failure mode "inversion" and the elementary behavior. Inversion is when the original sequence of the task is reversed by the operator. In this case, the elementary behaviors remember and move are observed.

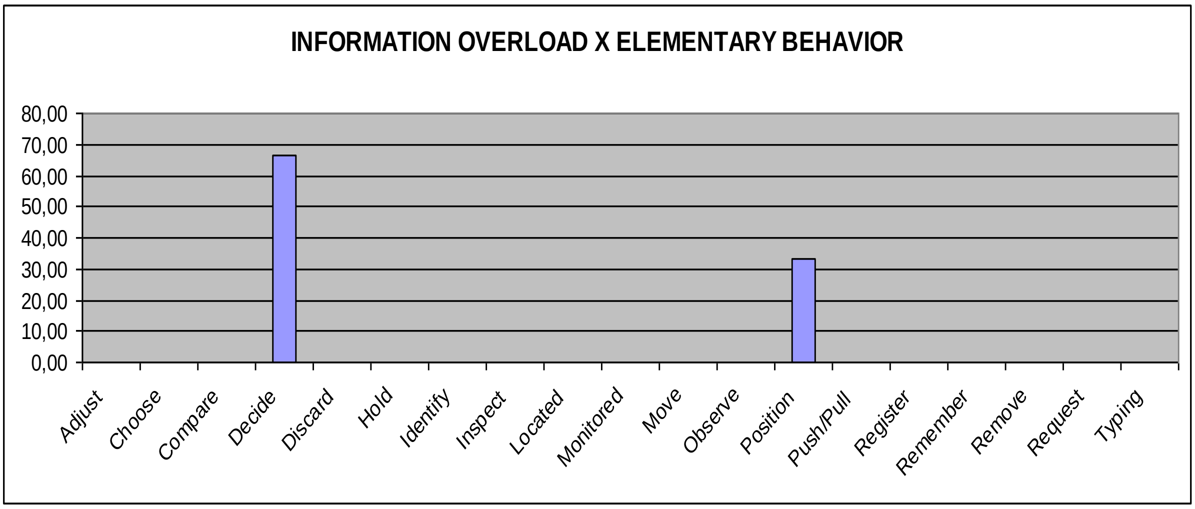


Figure 37 – Information overload x Elementary behavior

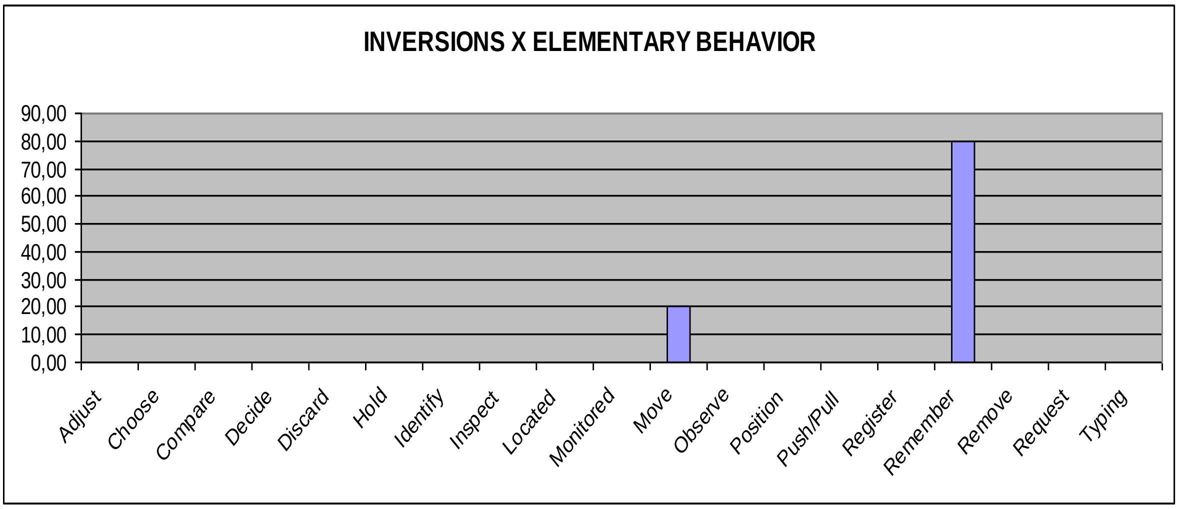


Figure 38 – Inversions x Elementary behavior

Figure 39 shows the relation between the failure mode “omission” and elementary behavior. Omission is when the operator, while performing a task, omits the next step that he should perform for the task, or he can omit all the steps accomplished of the task from a certain point. This usually occurs when he fails to check the state between two actions. This is required to determine when the first action is completed and the next should start. Remember is the elementary behavior presents in this case.

Figure 40 shows the relation between the failure mode “omission following interruptions” and elementary behavior. Omission following interruptions is when the operator performing a routine task, he is interrupted by an event and when he returns to resume what he was doing, he can not remember at what point he was before the break, failing to execute a step. From the analyzed data, only the elementary behavior monitored was observed.

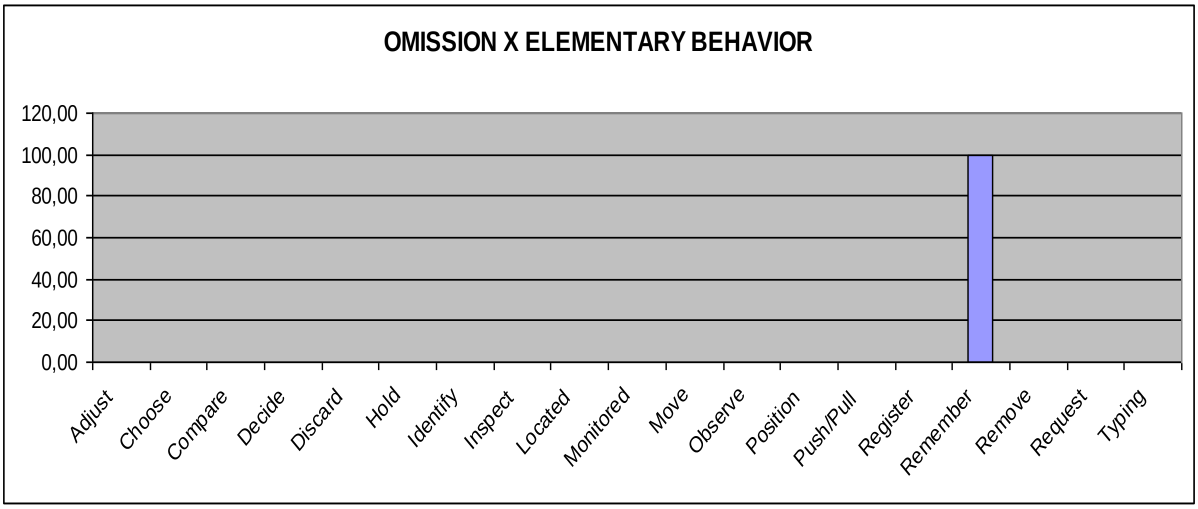


Figure 39 – Omission x Elementary behavior

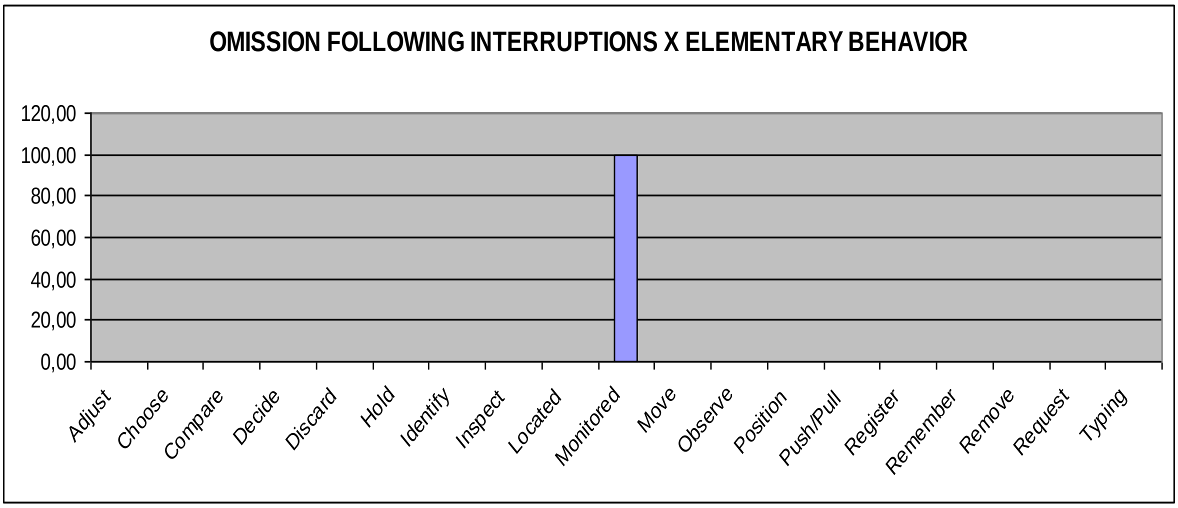


Figure 40 – Omission following interruptions x elementary behavior

Figure 41 shows the relation between “overconfidence” and elementary behavior. Overconfidence is when the operator will tend to justify his chosen course of action by focusing on evidence that favors it and by disregarding contradictory signs. Four elementary behaviors on this case were observed: decide, identify, position and typing.

Figure 42 shows the relation between “perceptual confusions” and elementary behavior. Perceptual confusions is when operators perform tasks without paying due attention to what they are doing. Many elementary behaviors are present in this case, but “identify” is the most relevant.

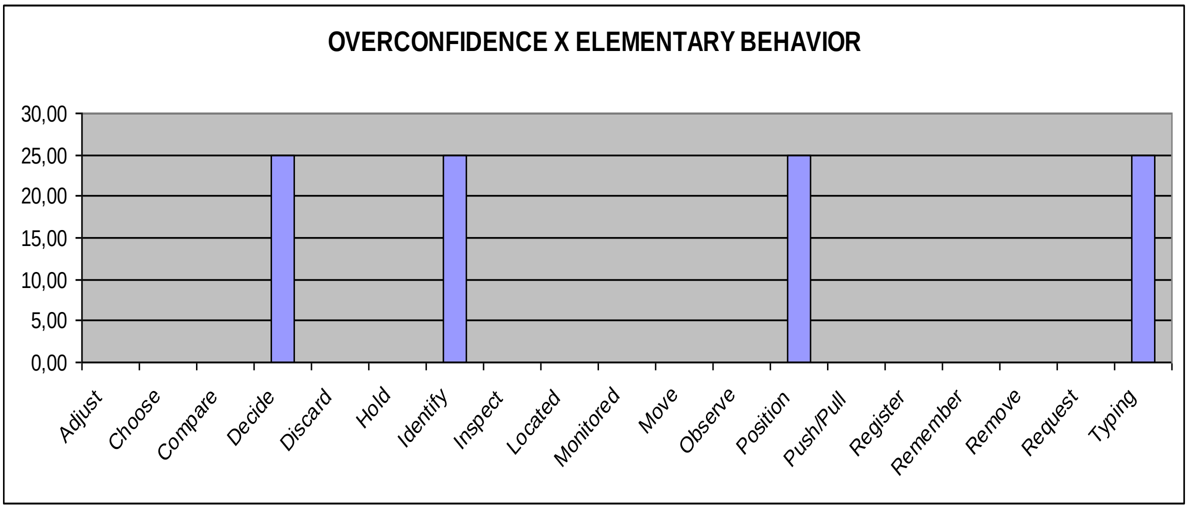


Figure 41 – Overconfidence x Elementary behavior

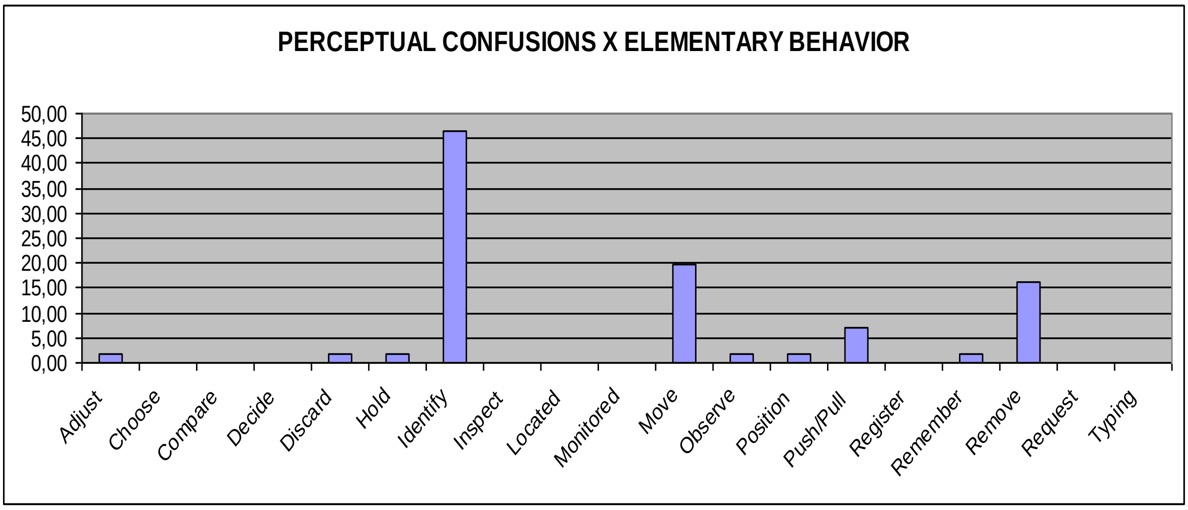


Figure 42 – Perceptual confusions x Elementary behavior

Figure 43 shows the relation between “rigidity” and elementary behavior. Rigidity is when the operator tends to reapply, over and over, a rule that achieved successful outcomes in the past. This situation emerges during the elementary behavior adjust and decide.

Figure 44 shows the relation between “rule strength” and elementary behavior. Rule strength is when this rule became a strong rule and the operator can trigger this rule when some but not all conditions are satisfied. This failure mode emerges when the elementary behavior decide, identify and push-pull occurred.

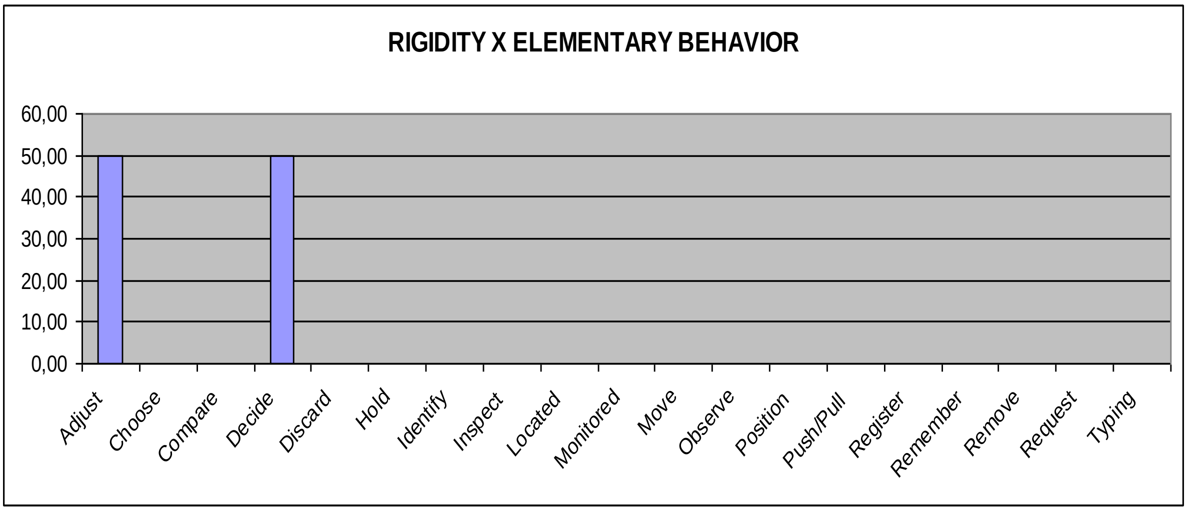


Figure 43 – Rigidity x Elementary Behavior

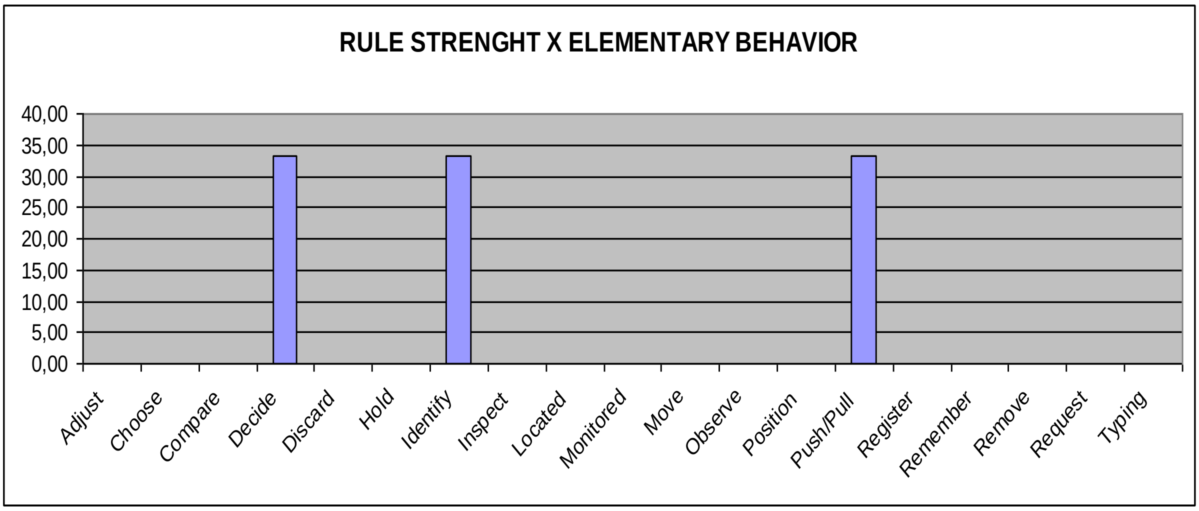


Figure 44 – Rule strength x Elementary behavior

Failure mode x Berliner process

The relation among these variables is analyzed below.

Figure 45 shows the relation between action deficiencies and Berliner process. Only during communication it was not observed the failure mode action deficiencies.

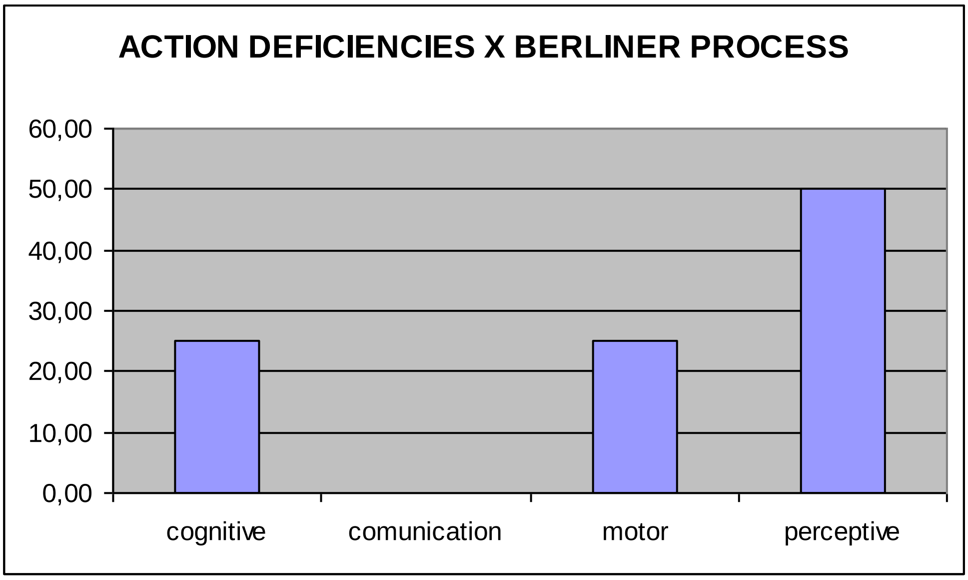


Figure 45 – Action deficiencies x Berliner process

Figure 46 shows the relation between biased reviewing and Berliner process. The failure mode biased reviewing was strongly observed during the Berliner cognitive process and with less importance than the motor process.

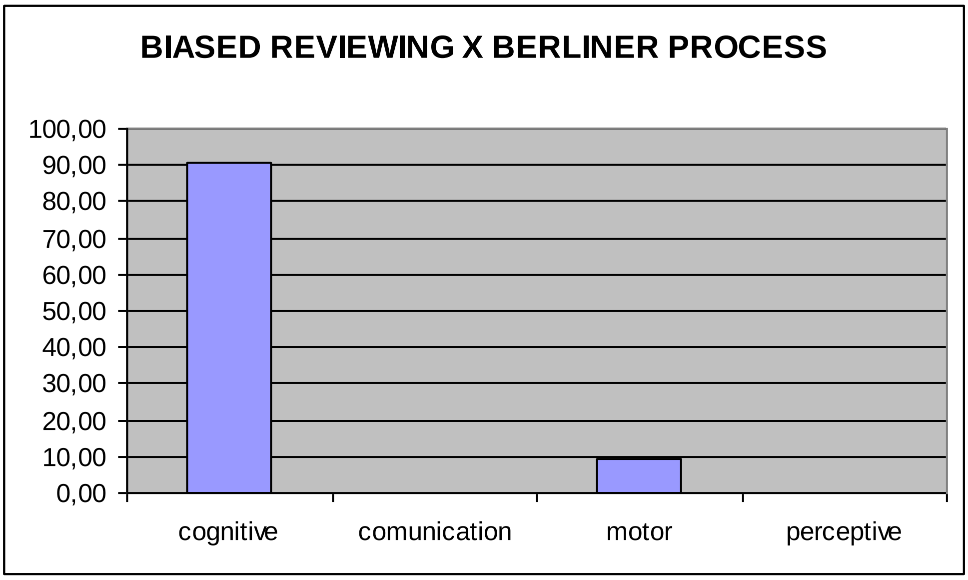


Figure 46 - Biased reviewing x Berliner process

Figure 47 shows the relation between confirmation bias and Berliner process. The failure mode confirmation bias was observed only during the cognitive process.

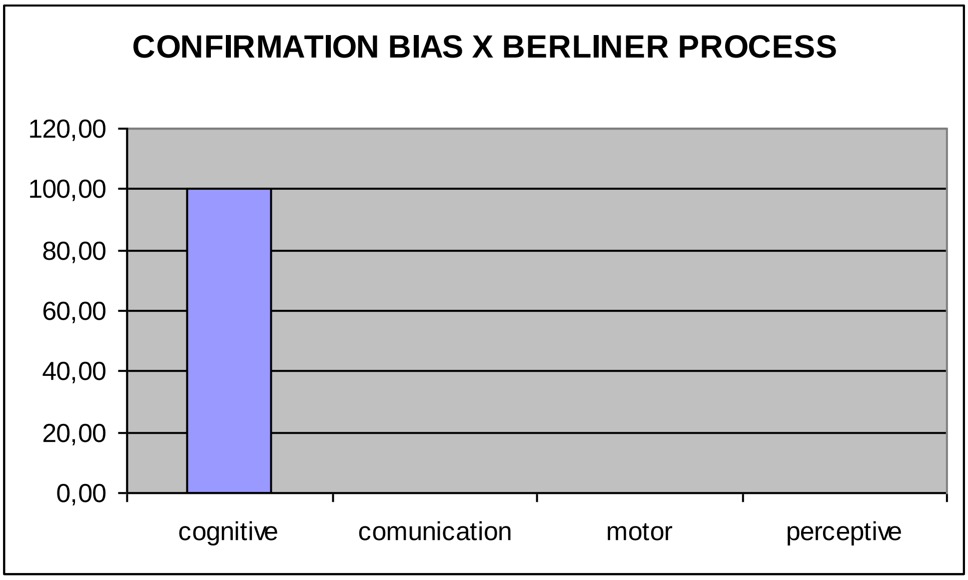


Figure 47 – Confirmation bias x Berliner process

Figure 48 shows the relation between countersigns and non signs and the Berliner process. The failure mode countersigns and non signs was observed for all the Berliner process.

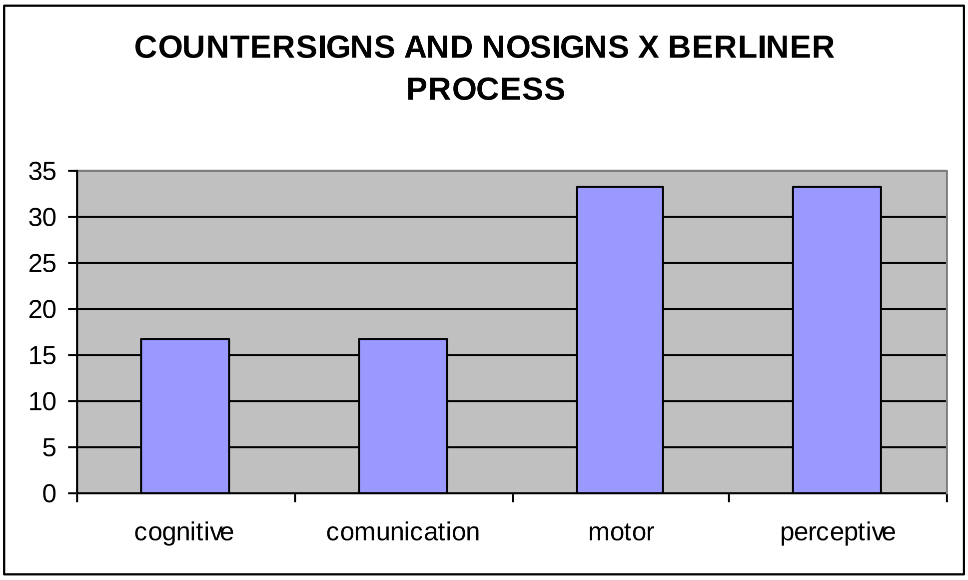


Figure 48 – Countersigns and non signs x Berliner process

Figure 49 shows the relation between encoding deficiencies and Berliner process. The cognitive process is more relevant.

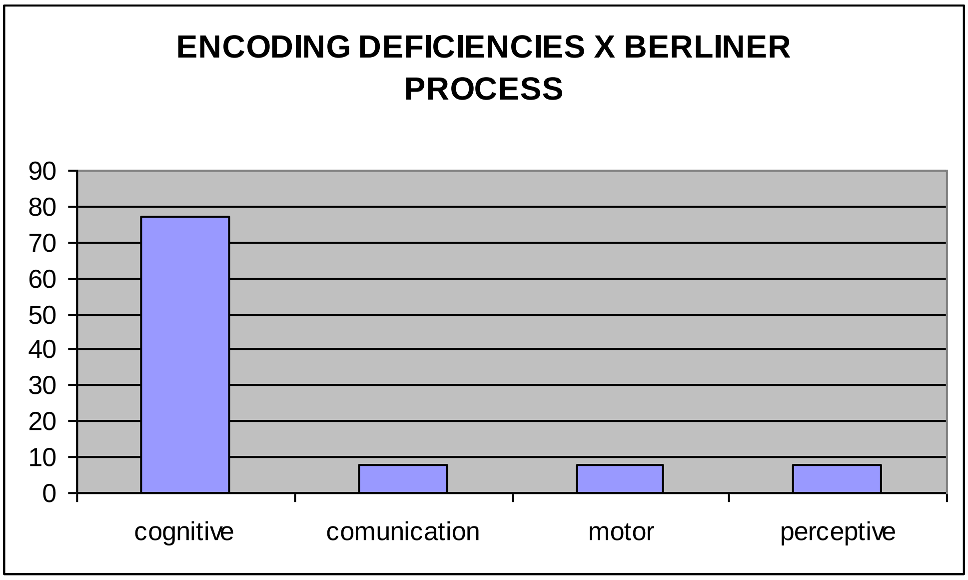


Figure 49 – Encoding deficiencies x Berliner process

Figure 50 shows the relation between first exceptions and Berliner process. Only motor process was observed in relation to the failure mode first exceptions.

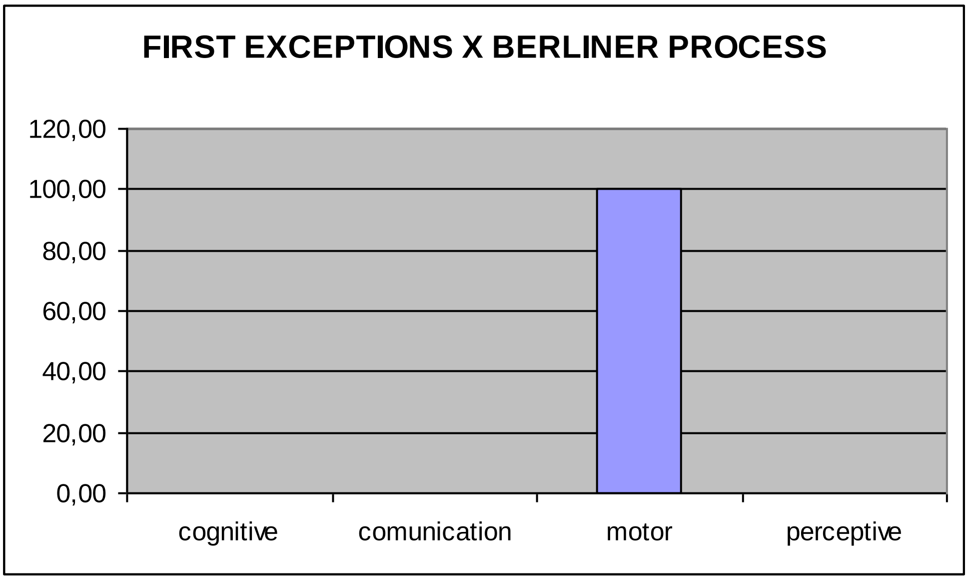


Figure 50 – First exceptions x Berliner process

Figure 51 shows the relation between general rule and non signs and Berliner process. Only the cognitive process was observed in relation to the failure mode general rule.

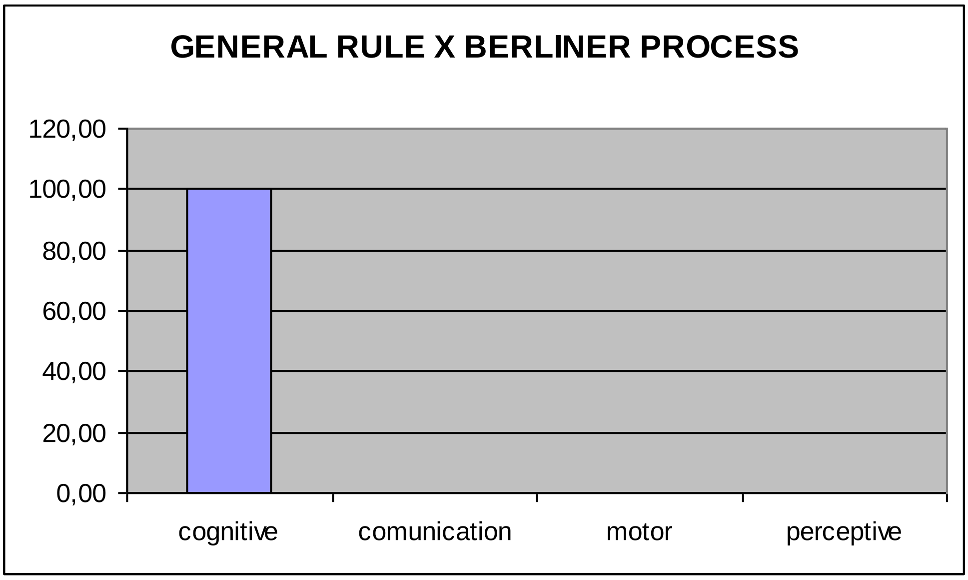


Figure 51 – General rule x Berliner process

Figure 52 shows the relation between information overload and Berliner process. Cognitive and motor process were observed.

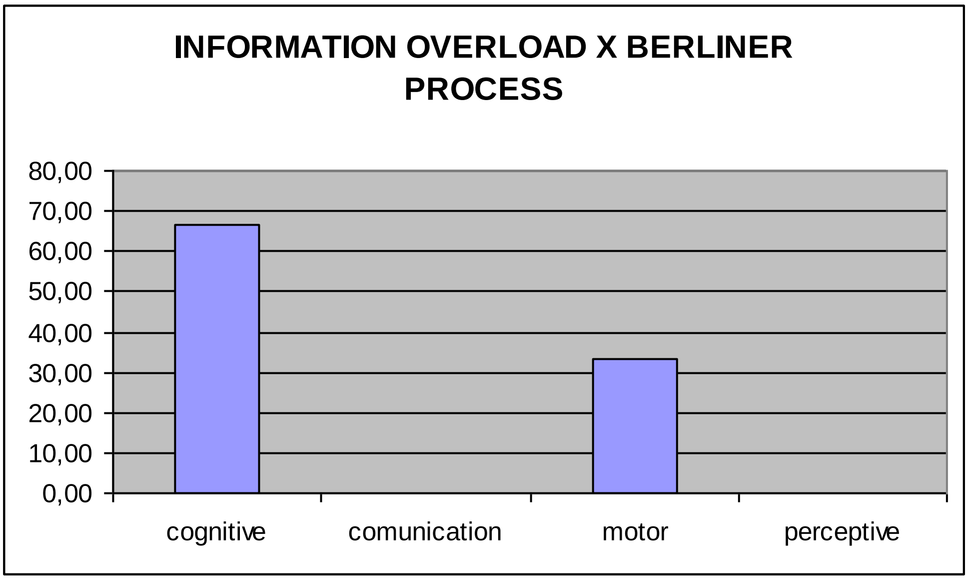


Figure 52 – Information overload x Berliner process

Figure 53 shows the relation between inversions and Berliner process. Mainly the cognitive process and the less motor process were observed in relation to the failure mode inversions

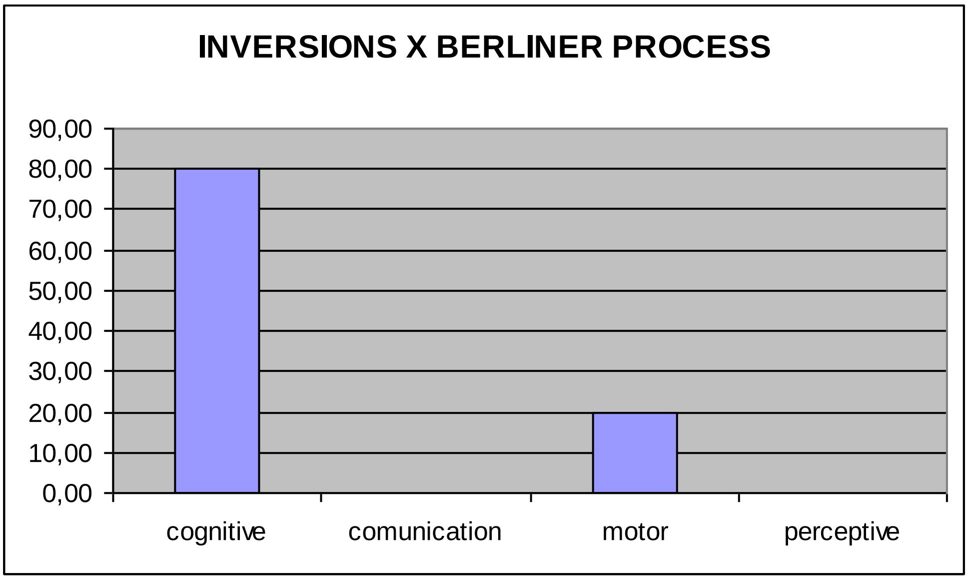


Figure 53 – Inversions x Berliner process

Figure 54 shows the relation between the failure mode "omission" and Berliner process. In this case, only the cognitive process was observed.

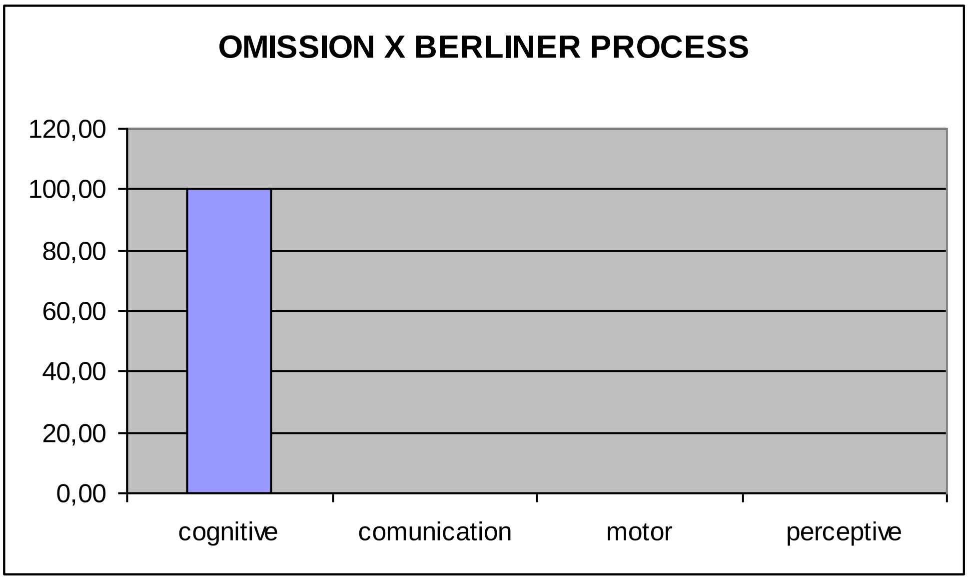


Figure 54 – Omission x Berliner process

Figure 55 shows the relation between the failure mode: "omission following interruptions" and Berliner process. In this case only the perceptive process was observed.

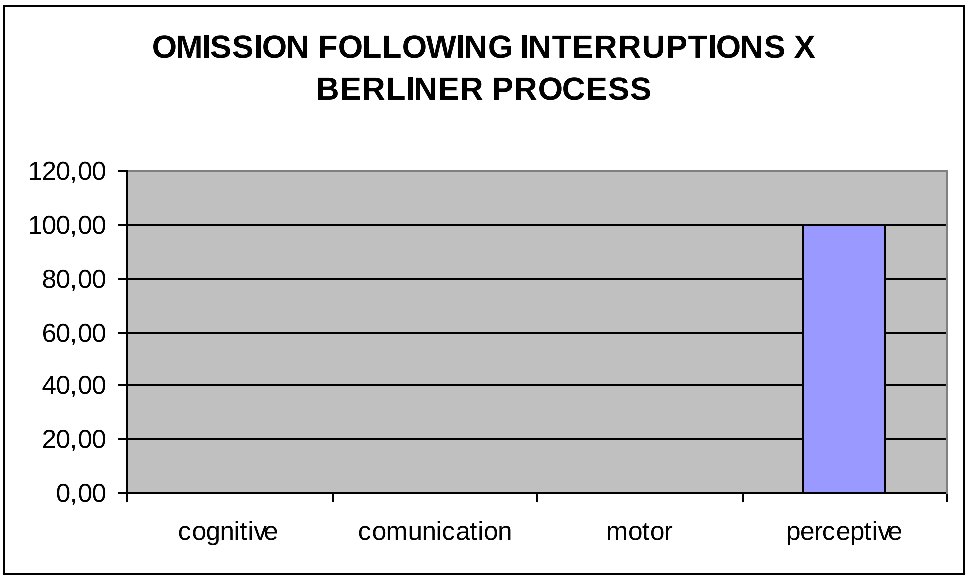


Figure 55 – Omission following interruptions x Berliner process

Figure 56 shows the relation between the failure mode: "overconfidence" and Berliner process. In this case only the communication process was not observed.

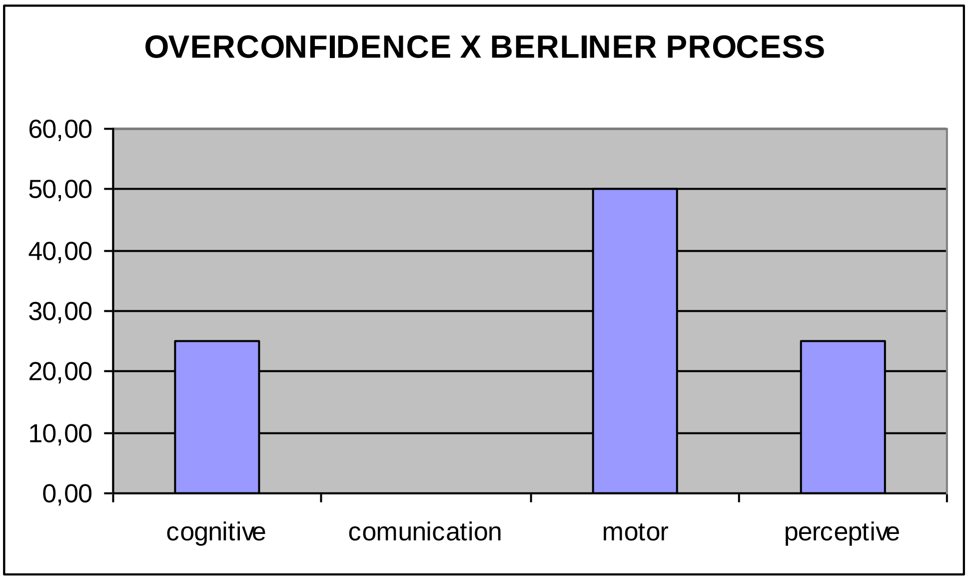


Figure 56 – Overconfidence x Berliner process

Figure 57 shows the relation between "perceptual confusions" and Berliner process. Only communication was not observed in this case.

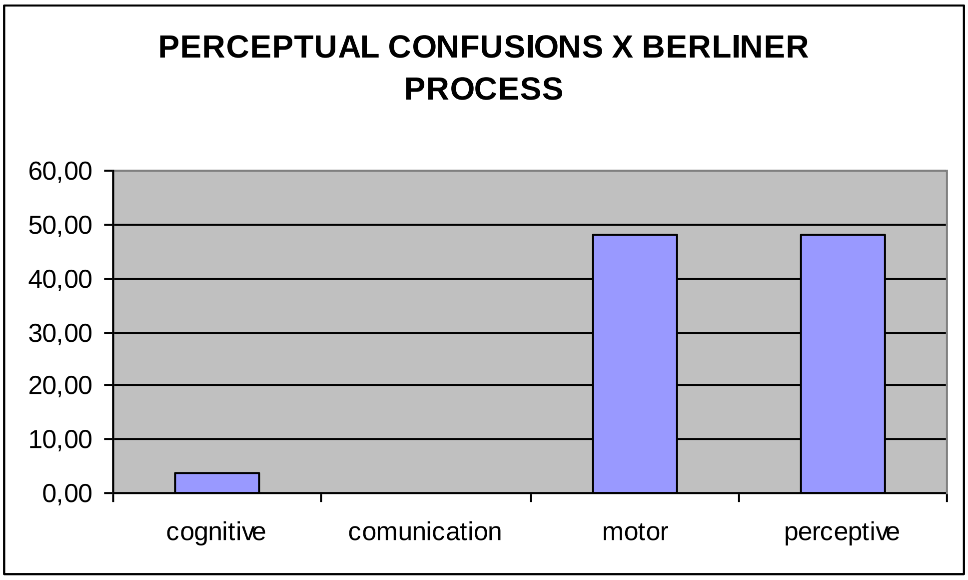


Figure 57 – Perceptual confusions x Berliner process

Figure 58 shows the relation between “rigidity” and Berliner process. Both cognitive and motor are relevant in this case.

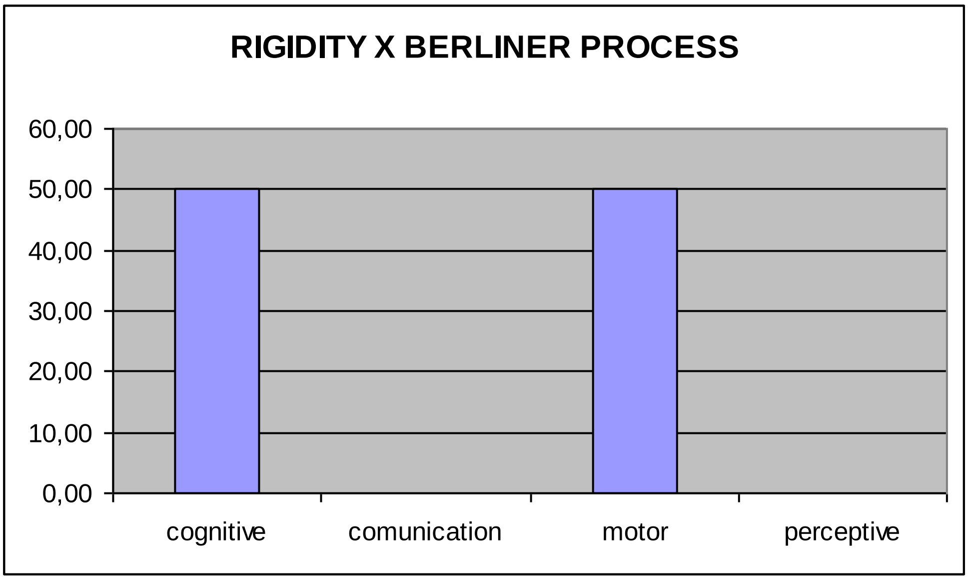


Figure 58 – Rigidity x Berliner process

Figure 59 shows the relation between the failure mode: “rule strength” and Berliner process. Only communication was not observed in this case.

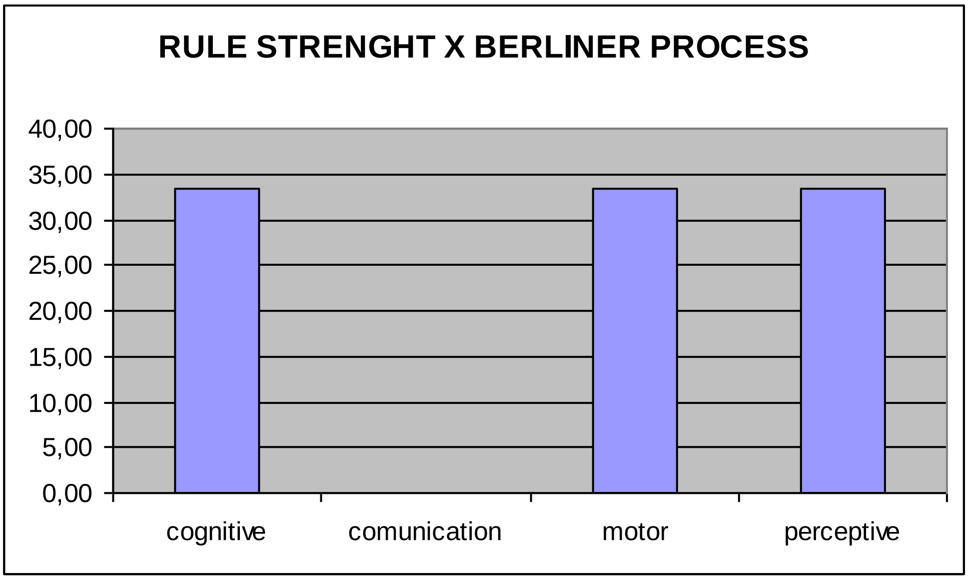


Figure 59 – Rule Strength x Berliner process

Error type x elementary behavior

According to Reason (1990), there are three types of error: Slip, Lapse and Mistake. "Slips and lapses are errors which result from some failure in the execution and/or storage stage of action sequence, regardless of whether the plan which guided them was adequate to achieve its objective". The main difference of slip and lapse is that whereas slips are observable as unplanned externalized actions, the lapses involve memory failures. "Mistakes may be defined as deficiencies or failure in the judgmental and/or inferential process involved in the selection of an objective or in the specification of the means to achieve it, irrespective of whether or not the actions directed by this decision-scheme run according to plan".

Figure 60 shows the relation between "lapse" and elementary behavior. The elementary behaviors: adjust, decide, monitor and move were observed in this case but "remember" presents is more frequent.

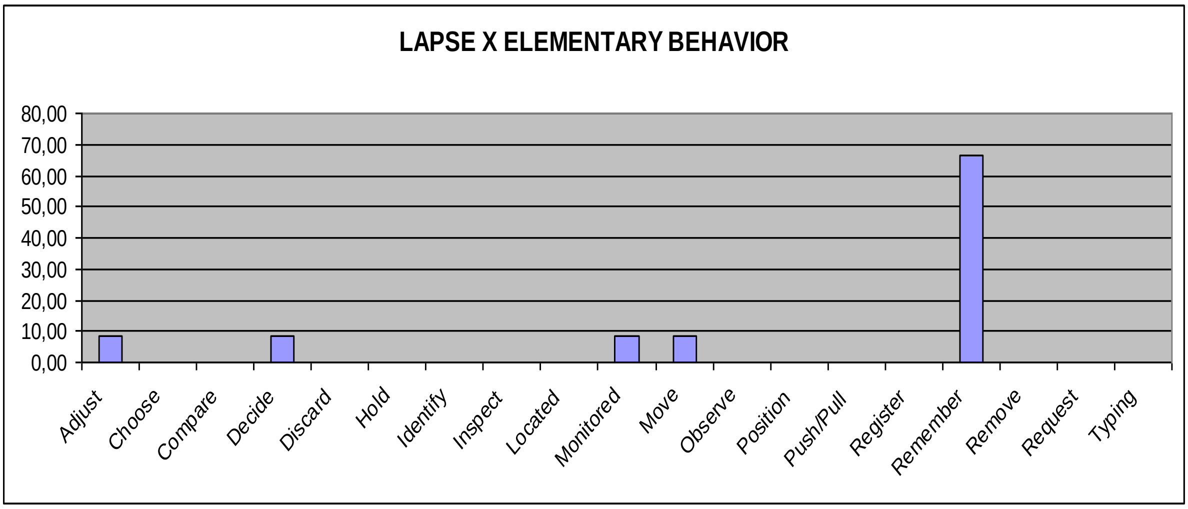


Figure 60 – Lapse x Elementary behavior

Figure 61 shows the relation between "mistake" and elementary behavior. Although many elementary behaviors are observed, "compare" and "decide" are more frequent.

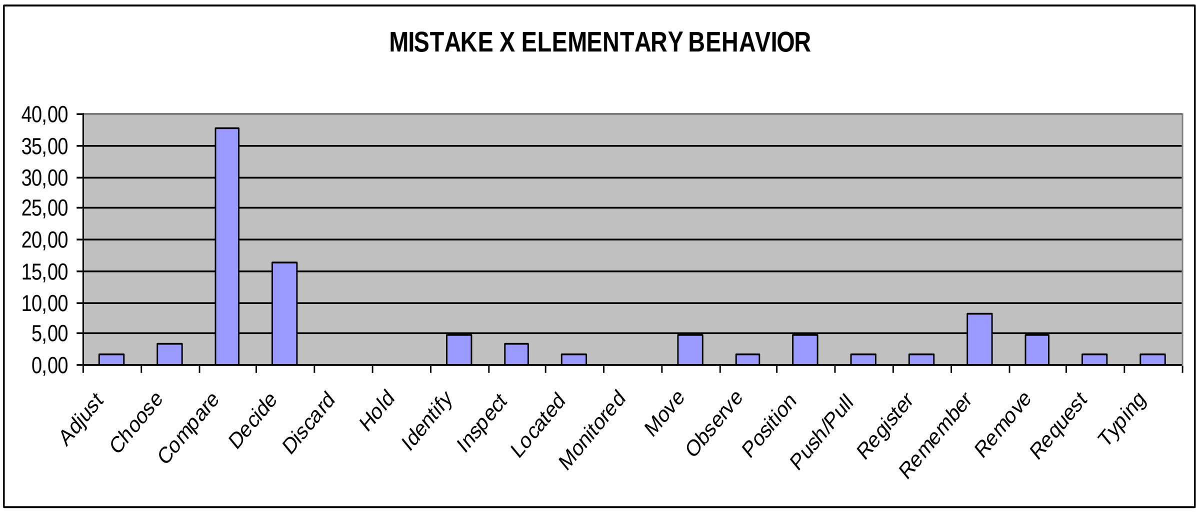


Figure 61 – Mistake x elementary behavior

Figure 62 shows the relation between "slip" and elementary behavior. Decide, discard, hold, monitor, move observe, position, push-pull, remember and remove are elementary behaviors that take to slip, however, identify is more frequent.

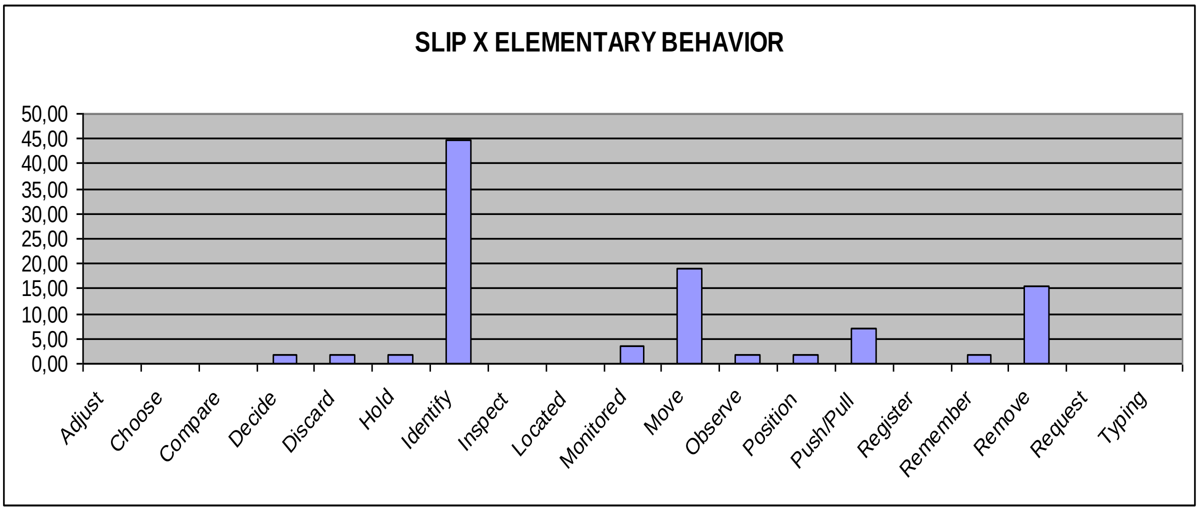


Figure 62 – Slip x Elementary behavior

Error type x Berliner process

Figure 63 shows the relation between "lapse" and Berliner process. Only "communication" was not observed in this case.

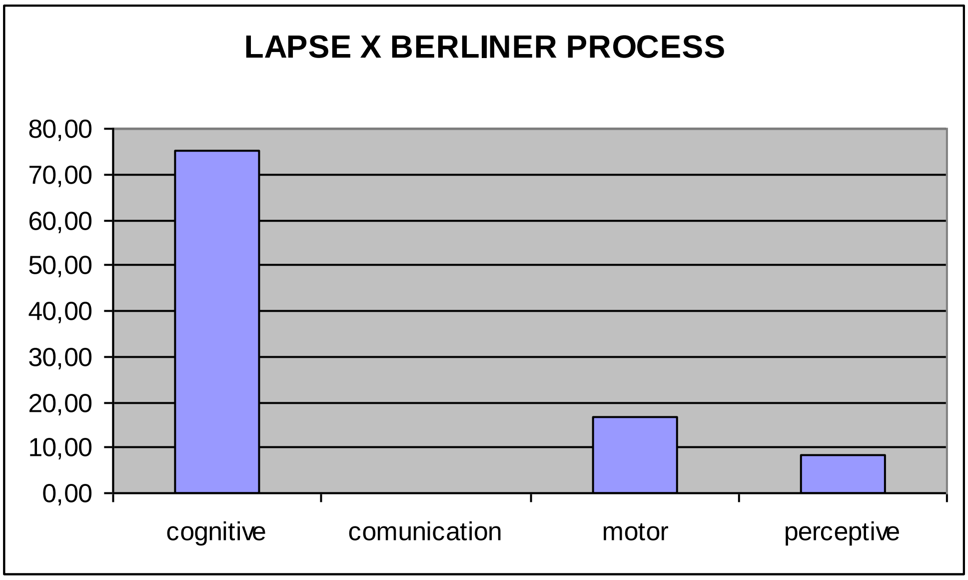


Figure 63 – Lapse x Berliner process

Figure 64 shows the relation between "mistake" and Berliner process. All Berliner processes were observed in this case, however the Berliner process "cognitive" is more frequent.

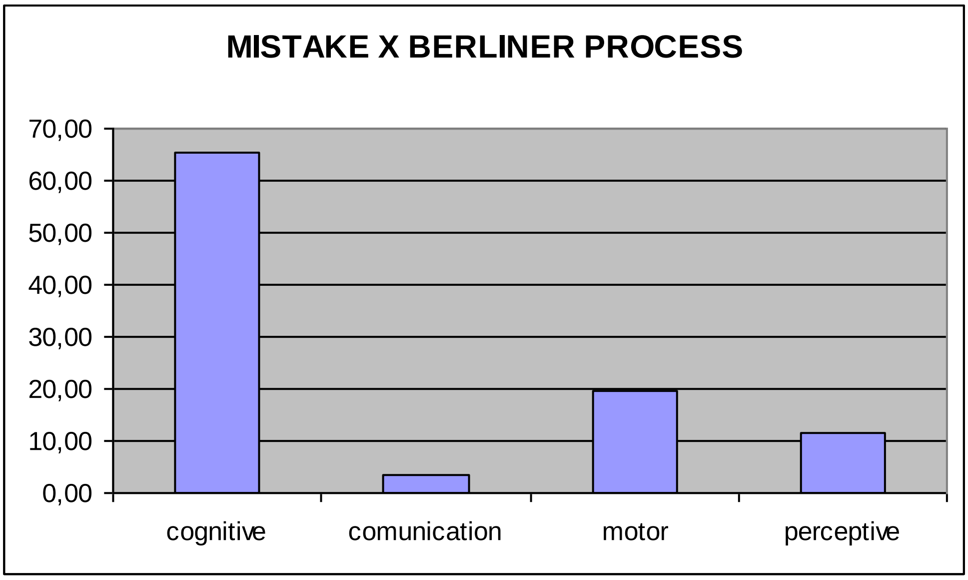


Figure 64 – Mistake x Berliner process

Figure 65 shows the relation between “slip” and Berliner process. Only “communication” was not observed in this case.

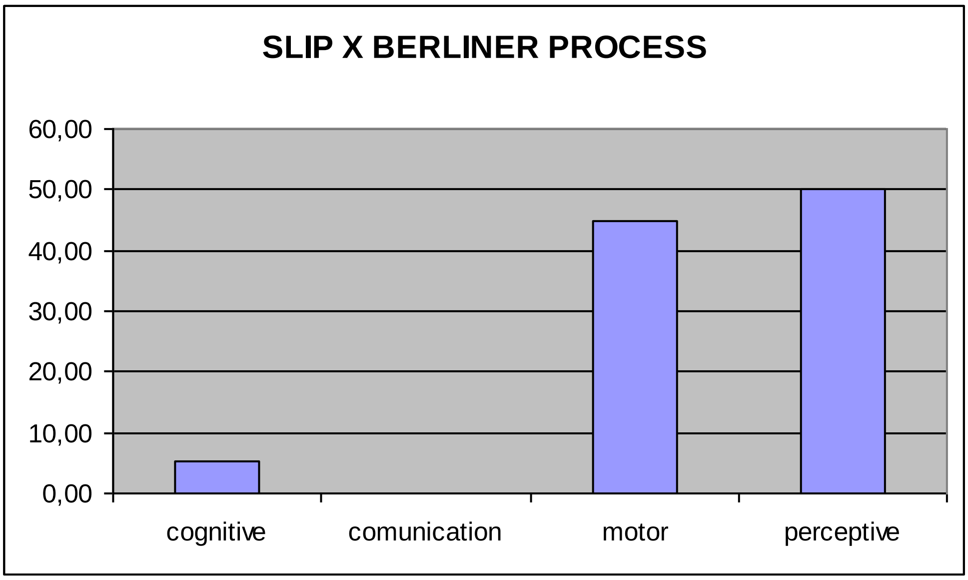


Figure 65 – Slip x Berliner process

Error domain x elementary behavior

Rasmussen (1982) presents the human error in three domains:

Skill-based, tasks that require manual skills; “In the skill-based domains, including automated, more or less subconscious routines, performance is controlled by stored patterns of behavior in a time-space domain. Errors are related to variability of force, space or time coordination”

Rule-based, tasks based on predefined procedures, require training; “The rule-based domain includes performance in familiar situations controlled by stored rules for coordination of subroutines, and errors are typically related to mechanisms like wrong classification or recognition of situations, erroneous associations to tasks, or to memory slips in recall of procedures”; and

Knowledge-based, complex tasks, require decision, require attention; “The third behavioral domain is called upon in case of unique, unfamiliar situations for which actions must be planned from an analysis and decision based on knowledge of the functional, physical properties of the system and the priority of the various goals. In this domain, the internal data processing functions used for the task are very person and situation dependent and vary with details in the task context, with the extent and type of knowledge immediately available to the person, and with his subjective preferences. In general, errors in this domain can only be defined in relation to the goal of the task and generic error mechanisms can only be defined from very detailed studies based on verbal protocols which can supply data on the actual data process”.

Figure 66 shows the relation between the domain “knowledge” and elementary behavior. In this domain, the elementary behaviors: compare, decide and remember, were more observed.

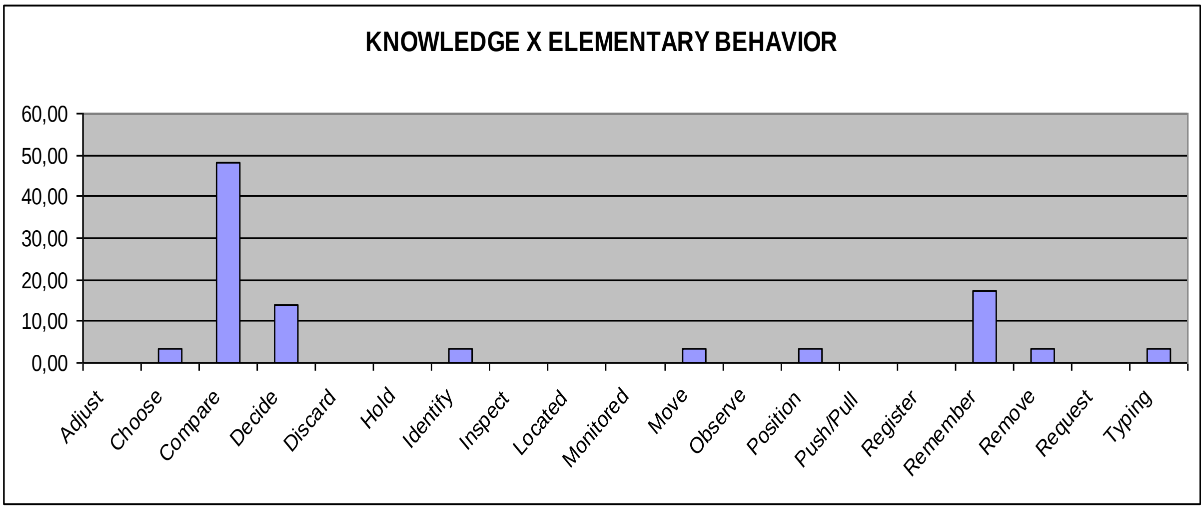


Figure 66 – Knowledge x Elementary behavior

Figure 67 shows the relation between the “rule” domain and elementary behavior. In this case, almost all elementary behaviors were present on “rule” domain, however compare and decide were more frequent.

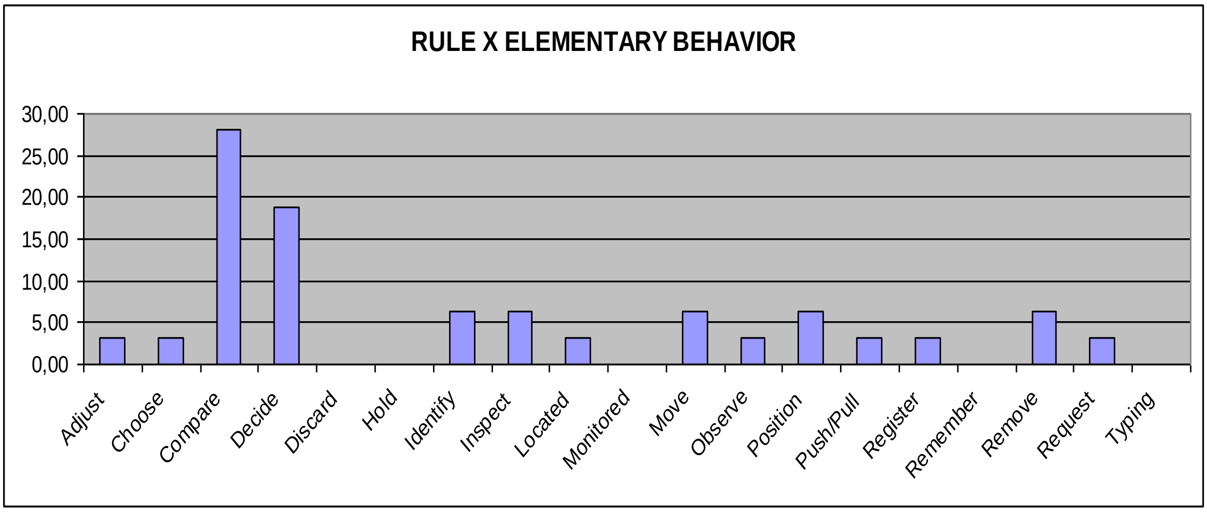


Figure 67 – Rule x Elementary behavior

Figure 68 shows the relation between "skill" domain and elementary behavior. The elementary behavior "identify" was more frequent.

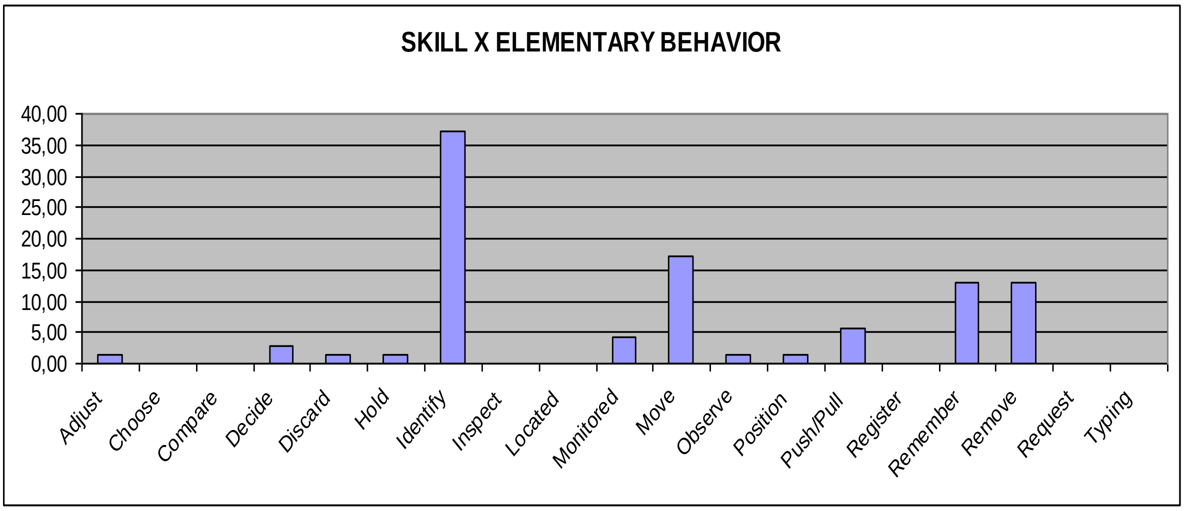


Figure 68 – Skill x Elementary behavior

Error domain x Berliner process

Figure 69 shows the relation between the domain "knowledge" and Berliner process. The Berliner process "communication" was not observed, whereas "motor" and "perceptive" appeared a few, however the Berliner process "cognitive" was more frequent.

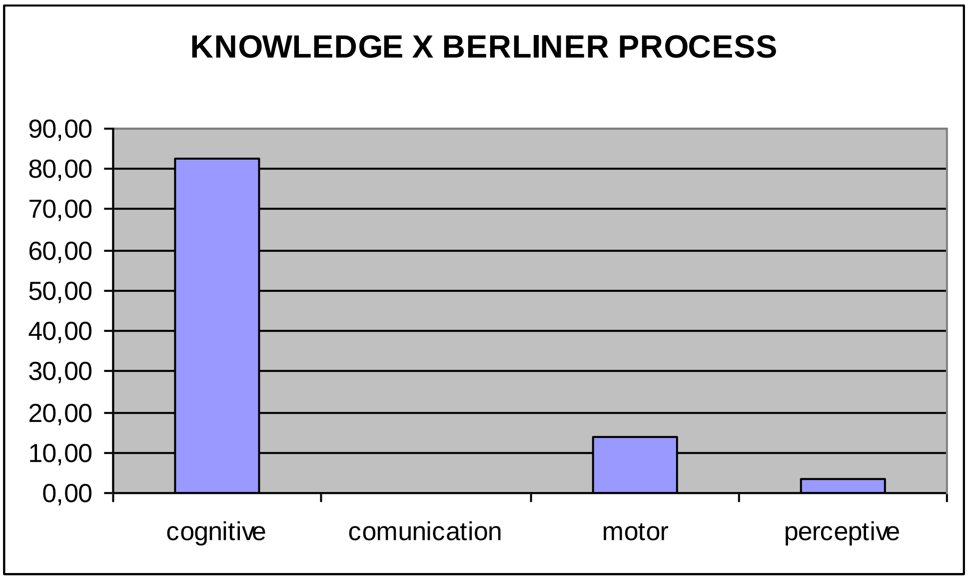


Figure 69 – Knowledge x Berliner process

Figure 70 shows the relation between the domain “rule” and Berliner process. All Berliner processes were observed in this case.

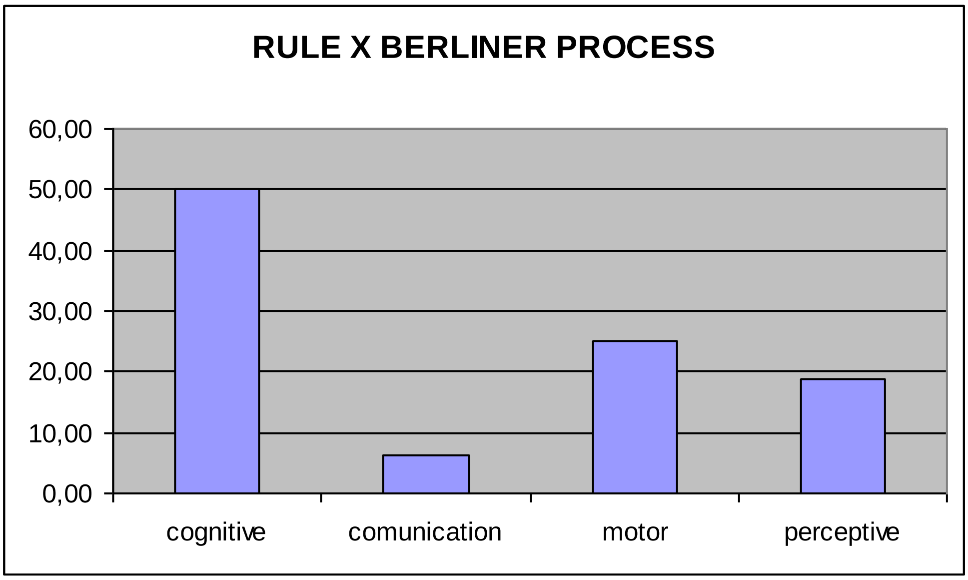


Figure 70 – Rule x Berliner process

Figure 71 shows the relation between the domain “skill” and Berliner process. Only “communication” was not observed in this case.

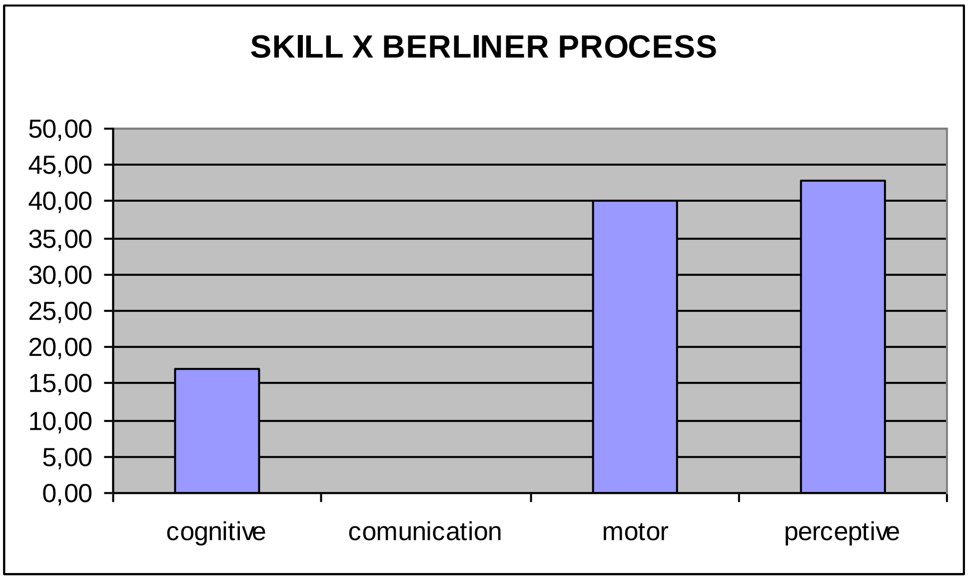


Figure 71 – Skill x Berliner process

The figures presented in this chapter contain important information about the nature of human errors in the Brazilian hydroelectrical sector. These data, shown in graphical form, when studied as a whole can provide subsidies for construction programs for reduction of human errors. Descriptive statistics despite to analyze only facts that already occurred, indicates probable trends in various processes that are ongoing. Some of these trends can be reversed if they are pointed out and prove harmful.

In the next chapter will be used tools that can quantify the probability of occurrence of human error and so along with the descriptive statistics to create a more robust programs for reduction of human errors in hydroelectric power companies.

6. ASSESSEMENT OF HUMAN ERROR USING THE NEW TAXONOMY AND MODEL OF ERROR SEQUENCE PROCESS

This chapter presents a methodology to apply the taxonomy and model proposed in Chapter 4 and presents examples using data collected from a Brazilian hydroelectric power company. Firstly, qualitative applications will be presented and next a quantitative application using Bayesian Networks will be presented.

6.1 Qualitative Applications

Having a robust taxonomy to classify human error is important, because through the data collected using this taxonomy it is possible to build a database to help the decisor makers to formulate policies of reduction of human error during operating and maintenance of electric power systems. A robust taxonomy helps to understand where the problems are, and through a quantitative model (for example, based on Bayesian Networks) to find what is more likeld to happen.

To create a database with robust and reliable information takes time, persistence and a good methodology. It is necessary to collect data in an easy and quick manner and without errors.

The proposed taxonomy in this work and the new cognitive models are adequate to create a robust database to store human error information from hydroelectric power companies.

Two types of performances are the main responsible for human error on power electric Companies: the operation and the maintenance program of the electric system.

Maintenance programs consist of preventive and predictive maintenance of transmission lines, substations and generator parks. The human error caused by the maintenance worker leads to outages of equipments and, as a consequence, in many times to load interruption.

Operation of hydroelectric power systems is an activity performed by operators in control rooms in substations and generating plants. The human error caused by the operator, usually leads to load interruption.

In the sequence, it will be presented a methodology to investigate human errors and how to store information using the proposed taxonomy and models developed in Chapter 4.

The models of human error report collected from a Brazilian hydroelectric power company, named RDFH (Report Shutdown by Human Error), (see Annex 2), is conveniently formatted so that it is possible to get all necessary and sufficient information for the construction of the table that supports the database development. For that it is necessary to perform a deep analysis of the human error report (RDFH) to get the necessary information to complete the table shown in Figure 72.

RDFH n°	Date	Interrupted load (MW)	Berliner process	Domain	Elementary behavior	Failure mode	Error type

Figure 72: Register Database

The RDFH n° is necessary to connect the human error with the task. The nature of the task is important to understand whether a specific set of tasks is causing more human error than others or which set of tasks produces a failure mode or elementary behavior. It is important also to infer the probability of failure with a specific set of tasks. In this work this will be achieved by means of BBN. During the analysis of the report (RDFH) it is necessary to identify which task step has immediately led to the human error, because this step is the most important to understand the nature of the error, and through this step it is possible to identify all other necessary registers to fill the database table. There is no simple recipe to identify the root step that caused the human error, it is necessary to be an expert on hydroelectric power systems and human reliability.

According to Figure 72, date is necessary to frame the period of time in which the human error occurred. The interrupted load is necessary to fix the importance of this occurrence. The higher interrupted load, the higher the fees.

The next five registers are the most important to assess the human error because they are the core of the model.

It is convenient to start with Domain**.** Choosing the correct domain is relatively easy, as it is necessary only to follow the diagram shown in Figure 14. In general, on routine works the domain is Skill-based because the worker does not choose the rule to perform a task. If the worker chooses the rule, the domain can be Rule-based. When the worker creates a new rule, the domain can be Knowledge-based. However, it is necessary to follow the diagram to correctly choose the domain. Once chosen the domain, the error type comes automatically.

In sequence, a pair Berliner process and elementary behavior can be chosen. Now it is very important to try to imagine what the worker was thinking when he faced the task. Berliner process is directly linked to elementary behavior. Berliner processes are four: cognitive, perceptive, motor and communication. A human error linked with communication process is when the elementary behavior is linked to exchange and/or recording information. Motor process is linked to the physical nature of the task, action that the worker needs physically to performe the task, like move or position an object. Perceptive process is linked with action like looking for and to receive information or to identify objects, events and actions. Cognitive process is when the worker needs to solve problems and makes a decision or to process information. Inside each Berliner process there are the respective elementary behaviors, but it is not very easy to choose the correct one because sometimes there are similarities between them. Practice and knowledge are essential to have success.

Finally, the most difficult and more important choice: failure mode. To choose the correct failure mode it is necessary firstly to know deeply each one of its definitions (see Table 3). Failure mode is linked with domain. Each domain has its own set of failures modes. Again practice and knowledge are essential to be successful.

After carefully analyzing the human error report and identified all registers, the database has to be filled. Now, some examples collected from Annex 1 will be presented.

Report error n. 083 September, 16 2004, load interrupted 70,00MW.

Summarized description: The accidental shutdown of circuit breakers 14G2 and 13T2 has as the root cause the failure to identify the sources of which one was defective and unduly control pushbutton reset from another source that presented itself to normal operation. (See RDFH in Annex 8)

The detailed analysis of this event reveals that:

1. The maintenance team was called because a circuit breaker was not working;
2. There is a written rule to identify faulty breaker;
3. The worker chose the correct rule;
4. The worker failed to choose the faulty breaker;
5. The worker shutdown the wrong breaker.

Comments:

- The worker was an expert and had several times correctly performed this kind of task;
- The worker chose a written rule;
- The worker chose the correct rule but wrongly performed a correct rule;
- The worker was on domain of Skill-based and committed a slip, according to Figure 14; (start task; There is a rule known to perform the task? Yes; Worker chooses the rule? Yes; Worker chooses the right rule? Yes; Worker performed the rule correctly? No; Skill-based Failure mode).
- In order to solve a problem and to make a decision, the worker wrongly chooses after considering many options. This is a pair of Berliner process: cognitive process and the elementary behavior: choose;
- The worker performed the task without paying due attention to what he was doing. This failure mode is: perceptual confusions.

Figure 73 shows sequence of error process for RDFH GRP-04/04.

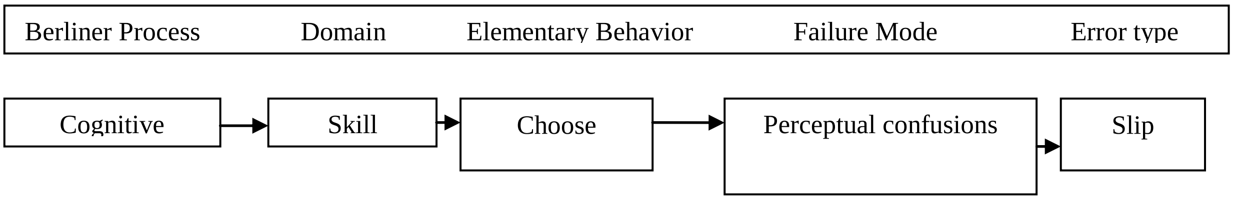


Figure 73: Sequence of error process RDFH GRP-04/04

The operator used the Cognitive process that is: to solve problems and to make a decision, to choose the faulty breaker, he perceived that there was a written rule and he chose the correct rule but he wrongly performed the correct rule, soon he was under the domain of Skill-based to perform the task. When the worker cognitively decided to perform the task, he committed a failure mode named perceptual confusions that is: operators perform tasks without paying due attention to what they are doing and committed a slip and the task was performed without success. Figure 73 shows the taxonomy and model to RDFH GRP-04/04.

Table 7 shows data filled in to Register Database after the analysis of the RDFH GRP-04/04.

Table 7: Register Database 1

RDFH n°	Date	Interrupted load (MW)	Berliner process	Domain	Elementary behavior	Failure mode	Error type
GRP-04/04	Sep 16 2004	70,00	Cognitive	Skill	Choose	Perceptual confusions	Slip

Report error n. GRP 04/2006 March, 22 2006, load interrupted 20,00MW.

Summarized description: When the worker was removing a cap of a cable on panel PCC13, he committed an unintentional touch. This touch caused the shutdown of breaker 52-1. (See RDFH in Annex 4)

The detailed analysis of this event reveals that:

1. The worker was removing a cap to performe a maintenance;
2. The worker had a rule to perform the job;
3. The job required to remove a cap to reach features inside the panel;
4. The worker unintentionally shutdown the 52-1 breaker.

Comments;

- The worker was an expert and had several times correctly performed this kind of task;
- The worker did not chose a rule;

- The worker was on domain of skill-based and committed a slip, according Figure 14; (start task; There is a rule known to perform the task? Yes; Worker chooses the rule? No; Rule was correctly written? Yes; Worker performed the rule correctly? No; skill-based Failure mode);
- In order to remove a cap to perform maintenance, the worker used Berliner process: motor and the elementary behavior: remove;
- The worker performed the task without paying due attention to what he was doing. This failure mode is: perceptual confusions**;**
- The worker committed a slip**.**

Figure 74 shows sequence of error process for RDFH GRP – 04/06.

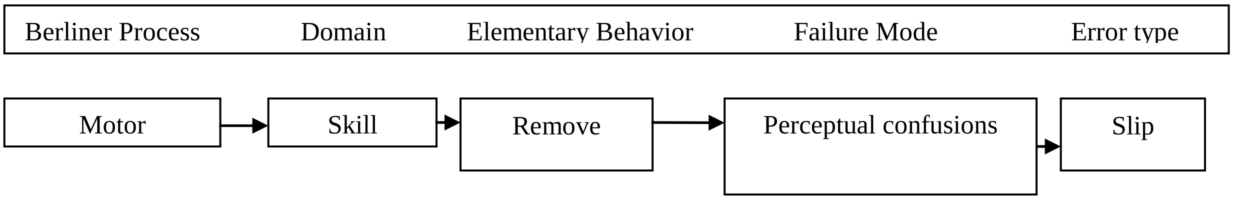


Figure 74: Sequence of error process RDFH GRP-04/06

The operator used the Motor process to remove a cap. He perceived that there was a written rule but he did not chose the rule. Thus he was under the domain of skill-based to perform the task. When the worker cognitively decided to perform the task, he committed a failure mode named perceptual confusions that is: operators perform tasks without paying due attention to what they are doing and committed a slip and the task was performed without success. Figure 74 shows the taxonomy and model to RDFH GRP-04/06.

Table 8 shows data filled in the Register Database after the analysis of the RDFH GRP-04/04 and RDFH GRP-04/06.

Table 8: Register Database 2

RDFH n°	**Date**	**Interrupted load (MW)**	**Berliner process**	**Domain**	**Elementary behavior**	**Failure mode**	**Error type**
GRP-04/04	Sep 16 2004	70,00	Cognitive	Skill	Choose	Perceptual confusions	Slip
GRP-04/06	Marc 22 2006	20,00	Motor	Skill	Remove	Perceptual confusions	Slip

Report error n. GRL 06/1999 November 25 1999, load interrupted 4,00MW.

Summarized description: The worker involved in the occurrence did not use the existing internal installation instruction to discriminate all the steps to be followed in the process of setting change relay. (See RDFH in Annex 5)

The detailed analysis of this event reveals that:

1. The worker had to adjust a specific relay;
2. The was written rule to perform this task;
3. The worker chose a wrong rule;
4. The worker incorrectly adjusted the relay (wrong values to pick up the relay).

Comments;

- The worker was an expert and had correctly performed this kind of task several times;
- The worker chose an incorrect rule, he trusted as in his memory to perform the task;
- The worker was on the domain of rule-based and committed a mistake, according to Figure 14; (start task; There is a rule known to perform the task? Yes; Worker chooses the rule? Yes; Worker chooses the right rule? No rule-based Failure mode).
- In order to adjust a relay, the worker used Berliner process: motor and the elementary behavior: adjust**;**
- The worker tried to apply, over and over, a rule that achieved successful outcome in the past, he chose a wrong rule to adjust the relay. This failure mode is: rigidity**;**
- The worker committed a mistake.

Figure 75 shows sequence of error process for RDFH GRL – 06/99.

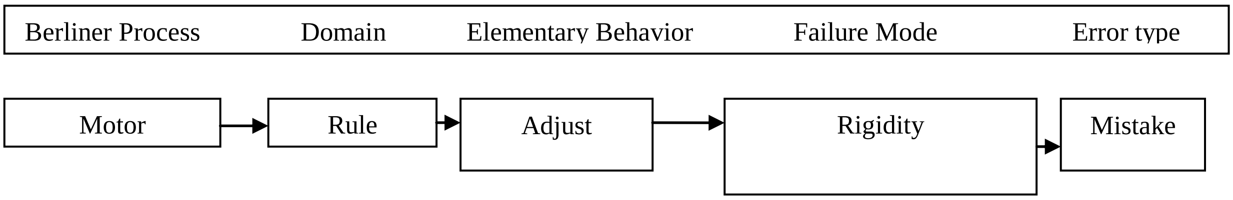


Figure 75: Sequence of error process RDFH GRL-06/99

The worker used the Motor process to adjust a relay, he perceived that there was a written rule but he did not choose the correct rule, soon he was under the domain of rule-based to perform the task. When the worker cognitively decided to perform the task, he committed a failure mode named rigidity that is: the operator tends to reapply, over and over, a rule that achieved successful outcomes it the past and committed a mistake and the task was performed without success. Figure 75 shows the taxonomy and model to RDFH GRL-06/99.

The Table 9 shows data filled in Register Database after the analysis of the RDFH GRP-04/04, RDFH GRP-04/06 and RDFH GRL-06/99.

Table 9: Register Database 3

RDFH n°	Date	Interrupted load (MW)	Berliner process	Domain	Elementary behavior	Failure mode	Error type
GRP-04/04	Sep 16 2004	70,00	Cognitive	Skill	Choose	Perceptual confusions	Slip
GRP-04/06	Marc 22 2006	20,00	Motor	Skill	Remove	Perceptual confusions	Slip
GRL-06/99	Nov 25 1999	4,00	Motor	Rule	Adjust	Rigidity	Mistake

Report error n. GRS 04/2007 July 5 2007, load interrupted 99,76MW.

Summarized description: Intervention to research: DC leakage to earth. The root cause was execution of high-risk task, without proper planning (See RDFH in Annex 6).

The detailed analysis of this event reveals that:

1. The worker had to find DC leakage to earth;
2. There was no written rule to perform this task;
3. The worker created a wrong rule;

Comments:

- The worker was an expert and had correctly performed this kind of task several times;
- This kind of task is difficult and has high risk of leading to a shutdown;
- The worker created a new rule to performe this task; He did not pay due time to carefully plan this high-risk rule;
- The worker was on domain of knowledge-based and committed a mistake, according to Figure 14; (Start task; There is a rule known to perform the task? No; Worker created a right new rule? No knowledge-based failure mode).
- In order to find DC leakage to earth, the worker used Berliner process: cognitive that is: to solve problems and to make a decision and the elementary behavior: decide that is: to get a conclusion based on a disposal information **;**

- The worker tends to justify his chosen course of action by focusing on evidence that favors it and by disregarding contradictory signs, thus creating a wrong rule. This failure mode is: overconfidence**;**
- The worker committed a mistake**.**

Figure 75 shows sequence of error process for RDFH GRS – 04/07.

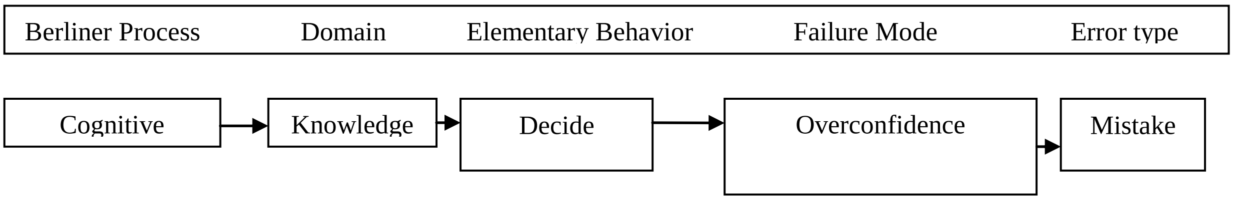


Figure 76: Sequence of error process RDFH GRS-04/07

The worker used the cognitive process to decide how to find a DC leakage to earth. He perceived that there was no written rule, thus he was under the domain of knowledge-based to perform the task. When the worker cognitively decided to perform the task, he committed a failure mode named overconfidence and committed a mistake and the task was performed without success. Figure 76 shows the taxonomy and model to RDFH GRS-04/07.

Table 10 shows data filled in Register Database after the analysis of the RDFH GRP-04/04, RDFH GRP-04/06, RDFH GRL-06/99 and RDFH GRS-04/07.

Table 10: Register Database 4

RDFH n°	**Date**	**Interrupted load (MW)**	**Berliner process**	**Domain**	**Elementary behavior**	**Failure mode**	**Error type**
GRP-04/04	Sep 16 2004	70,00	Cognitive	Skill	Choose	Perceptual confusions	Slip
GRP-04/06	Marc 22 2006	20,00	Motor	Skill	Remove	Perceptual confusions	Slip
GRL-06/99	Nov 25 1999	4,00	Motor	Rule	Adjust	Rigidity	Mistake
GRS-04/2007	July 5 2007	99,76	Cognitive	Knowledge	Decide	Overconfidence	Mistake

Report error n. GRO 02/2009 August 25 2009, load interrupted 15,10MW.

Summarized description: The team involved in the intervention carried out an analysis of performed tests. However, the risk of action of the breaker failure scheme 12T5 was not viewed, due to the fact that the one normally open contact switch 86-T5, used in project protection and control, has no direct function of the circuit breaker off 12T5. (See RDFH in Annex 6).

The detailed analysis of this event reveals that:

1. The worker was performing tests on a protection circuit;
2. There was no written rule to perform this task;
3. The worker created a wrong rule;

Comments:

- The team worker was an expert;
- This kind of task is difficult and has high risk of committing a shutdown;
- The worker created a new rule to perform this task; he did not check all possible possibilities;
- The worker was on domain of knowledge-based and committed a mistake, according to Figure 14; (Start task; There is a rule known to perform the task? No; Worker created a right new rule? No knowledge-based failure mode).
- In order to perform the tests, the worker used Berliner process: cognitive that is: to solve problems and to make a decision and the elementary behavior: compare, that is: to examine the characteristics or qualities of two or more objects or concepts, with proposal to identify similarities or differences**;**
- The worker thought that he checked all different factors, but he did not. Then he created a wrong rule. This failure mode is: biased reviewing**;**
- The worker committed a mistake**.**

Figure 77 shows sequence of error process for RDFH GRO – 02/09.

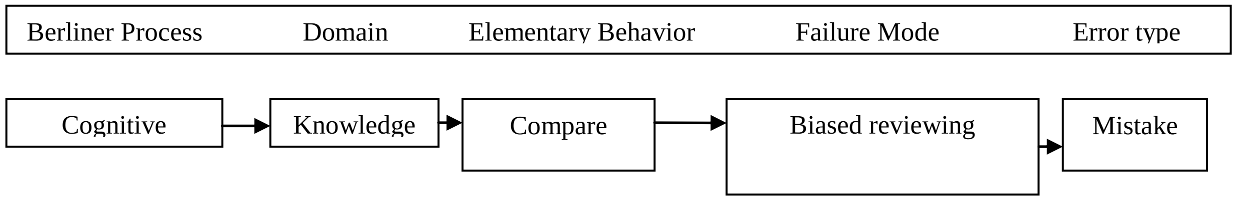


Figure 77: Sequence of error process RDFH GRO-02/09

The worker used the cognitive process to compare how to perform tests on a database protection circuit. He perceived that there was not written rule, thus he was under the domain of knowledge-based to perform the task. When the worker cognitively decided to perform the task, he committed a failure mode named biased reviewing and committed a mistake and the task was performed without success. Figure 77 shows the taxonomy and model to RDFH GRO-02/09.

Table 11 shows data filled in Register Database after the analysis of the RDFH GRP-04/04, RDFH GRP-04/06, RDFH GRL-06/99, RDFH GRS-04/07 and RDFH GRO-02/09.

Table 11: Register Database 5

RDFH n°	Date	Interrupted load (MW)	Berliner process	Domain	Elementary behavior	Failure mode	Error type
GRP-04/04	Sep 16 2004	70,00	Cognitive	Skill	Choose	Perceptual confusions	Slip
GRP-04/06	Marc 22 2006	20,00	Motor	Skill	Remove	Perceptual confusions	Slip
GRL-06/99	Nov 25 1999	4,00	Motor	Rule	Adjust	Rigidity	Mistake
GRS-04/2007	July 5 2007	99,76	Cognitive	Knowledge	Decide	Overconfidence	Mistake
GRO-02/2009	Aug 25 2009	15,10	Cognitive	Knowledge	Compare	Biased reviewing	Mistake

Report error n. STC 01/2005 January 10 2005, load interrupted 66,13MW.

Summarized description: The shutdown was the result of tests to verify the protections of the transmission line LT 02J4, and the transformer 04T1 of SE Santo Antonio de Jesus. (See RDFH in Annex 7).

The detailed analysis of this event reveals that:

1. The shutdown was automatic;
2. This is a latent failure; The protection team made a failure some time ago when performing an adjustment of the timing of this relay;
3. There was a correct written rule;
4. The worker chose a wrong rule;

Comments;

- The team worker were experts;
- This kind of task is a common one and the risk to committ a shutdown is low;
- The worker choose a wrong rule to perform this task;
- The worker was on domain of rule-based and committed a mistake, according to Figure 14; (Start task; There is a rule known to perform the task? Yes; Worker chooses the rule? Yes, Worker chooses the right rule? No, rule-based failure mode).
- In order to set up the timing of relay, the worker used Berliner process: cognitive, that is: to solve problems and to make a decision and the elementary

behavior: compare, that is: to examine the characteristics or qualities of two or more objects or concepts, with proposal to identify similarities or differences**;**

- The worker imagined that he encoded all different properties of the problem space, but he did not, choosing a wrong rule. This failure mode is: encoding deficiencies**;**
- The worker committed a mistake**.**

Figure 78 shows sequence of error process for RDFH STC – 01/05.

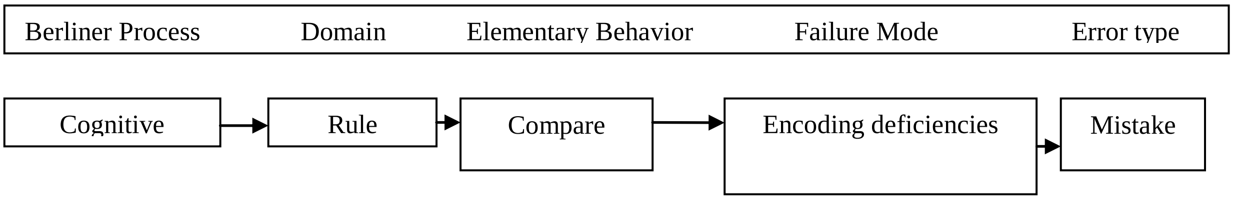


Figure 78: Sequence of error process RDFH STC-01/05

The worker used the cognitive process to compare how to set up the timing the relay. He perceived that there was a written rule, thus he was under the domain of rule-based to perform the task. When the worker cognitively decided to perform the task, he committed a failure mode named encoding deficiencies and committed a mistake and the task was performed without success. Figure 78 shows the taxonomy and model to RDFH STC-01/05.

Table 12 shows data filled in Register Database after the analysis of the RDFH GRP-04/04, RDFH GRP-04/06, RDFH GRL-06/99, RDFH GRS-04/07, RDFH GRO-02/09 and RDFH STC-01/05.

Table 12: Register Database 6

RDFH n°	**Date**	**Interrupted load (MW)**	**Berliner process**	**Domain**	**Elementary behavior**	**Failure mode**	**Error type**
GRP-04/04	Sep 16 2004	70,00	Cognitive	Skill	Choose	Perceptual confusions	Slip
GRP-04/06	Marc 22 2006	20,00	Motor	Skill	Remove	Perceptual confusions	Slip
GRL-06/99	Nov 25 1999	4,00	Motor	Rule	Adjust	Rigidity	Mistake
GRS-04/2007	July 5 2007	99,76	Cognitive	Knowledge	Decide	Overconfidence	Mistake
GRO-02/2009	Aug 25 2009	15,10	Cognitive	Knowledge	Compare	Biased reviewing	Mistake
STC-01/2005	Jan 19 2005	66,13	Cognitive	Rule	Compare	Encoding deficiencies	Mistake

Report error n. GRL 05/2003 Mai 08 2003, load interrupted 5,00MW.

Summarized description: In making the selection key 31C1-5, the operator was confused and selected the key 41C1-6. Both sides are set in the same chassis and have a common point although both keys were properly coded and clearly visible. (See RDFH in Annex 8).

A The detailed analysis of this event reveals that:

1. The operator was performing a general maneuver program;
2. There was a written rule to perform the task;
3. The operator did not choose the rule;

Comments;

- The operator was experienced;
- This kind of task is a common one and the risk to committ a shutdown is low;
- The worker did not choose a rule to performed this task;
- The worker was on domain of skill-based and committed a slip, according to Figure 14; (Start task; There is a rule known to perform the task? Yes; Worker chooses the rule? No; Rule was correctly written? Yes; Worker performed rule correctly? No; Skill-based Failure mode).
- In order to selected a key, the worker used Berliner process: perceptive that is: to identify objects, events and actions**;** and the elementary behavior: identify, that is: to acknowledge the nature or indication of an object, according to its implicit or predetermined characteristics;
- The worker performed the task without paying due attention to what he was doing. This failure mode is: perceptual confusions**;**
- The worker committed a slip**.**

Figure 79 shows sequence of error process for RDFH GRL – 05/03.

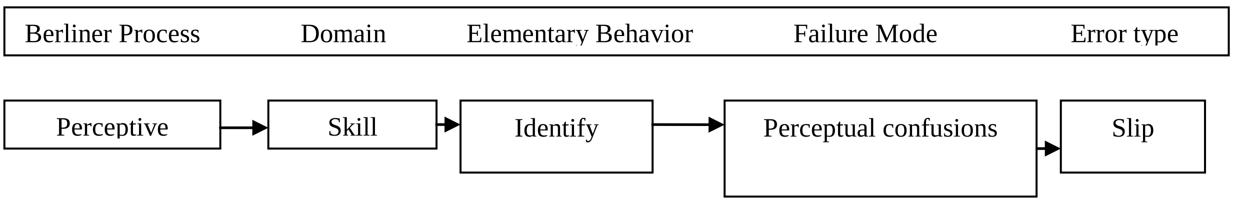


Figure 79: Sequence of error process RDFH GRL-05/03

The worker used the perspective process to identify a key to shutdown. He perceived that there was a written rule, but he did not choose this rule. Thus he was under the domain of

skill-based to perform the task. When the worker cognitively decided to perform the task, he committed a failure mode named perceptual confusions and committed a slip and the task was performed without success. Figure 79 shows the taxonomy and model to RDFH GRL-05/03.
Table 13 shows data filled in Register Database after the analysis of the RDFH GRP-04/04, RDFH GRP-04/06, RDFH GRL-06/99, RDFH GRS-04/07, RDFH GRO-02/09, RDFH STC-01/05 and RDFH GRL-05/03.

Table 13: Register Database 7

RDFH n°	Date	Interrupted load (MW)	Berliner process	Domain	Elementary behavior	Failure mode	Error type
GRP-04/04	Sep 16 2004	70,00	Cognitive	Skill	Choose	Perceptual confusions	Slip
GRP-04/06	Marc 22 2006	20,00	Motor	Skill	Remove	Perceptual confusions	Slip
GRL-06/99	Nov 25 1999	4,00	Motor	Rule	Adjust	Rigidity	Mistake
GRS-04/2007	July 5 2007	99,76	Cognitive	Knowledge	Decide	Overconfidence	Mistake
GRO-02/2009	Aug 25 2009	15,10	Cognitive	Knowledge	Compare	Biased reviewing	Mistake
STC-01/2005	Jan 19 2005	66,13	Cognitive	Rule	Compare	Encoding deficiencies	Mistake
GRL-05/2003	Mai 08 2003	5,00	Perspective	Skill	Identify	Perceptual confusions	Slip

6.2 Bayesian Networks

The Bayesian philosophy or subjective philosophy, assigns the value of a probability, the degree of belief of an individual. The degree of belief is a measure of a person's knowledge about a certain proposition or event according to Martz & Waller (1982).
For HRA, Bayesian inference seems more functional than empirical, due to which to infer about the true value of the probability of human error empirically, ie, frequentist, one must find the "number of opportunities for error."
However, this identification process is difficult for individuals since events do not occur under the same conditions. Unlike equipment, people can learn from their mistakes. Therefore, even though the external environment can be maintained constant, it is impossible for a person to encounter with the same position twice with the same degree of experience.
In general, inferring the "true value" of probability of the events, subjectively, has advantage over frequentist way because, besides using information from experiments can also quantify the experience of individuals

The subjective probability is called Bayesian by making use of Bayes' theorem.

Let two events A e E, such that $P(A) > 0$ and $P(E) > 0$:

$$P(A \mid E) = \frac{P(E \mid A)P(A)}{P(E)} \tag{5.1}$$

where:

$P(A)$ is the a priori probability of event A;

$P(E|A)/P(E)$ is the relative likelihood of the evidence and, assuming the occurrence of the event A;

$P(A|E)$ is the posteriori probability of event A given the evidence E.

The Bayesian inference is relatively simple when it involves only two variables. However, when the number of variables increases, such inference becomes complex and without practical value according to Neapolitan (2004). Faced with this difficulty, Bayesian networks are recommended to treat complex systems.

Bayesian networks are graphical structures that allow us to represent reasons or arguments in the field of uncertainty according to Korb & Nicholson (2003).

The nodes in Bayesian networks represent the random variables (discrete or continuous). The arcs represent the connections or direct dependencies between variables. Directed connections are always causal, ie the direction of the arcs represents the cause and effect relationships between variables. For example, if there is an arc going from node A to node B, it is assumed that node A is a probable cause of B and the nomenclature adopted as A is a parent B. More generally, A is the ancestor of B and B is a descendant of A if there is a path from A to B. If the node has no parents, it is called the root node.

The random variables are quantified by a distribution of conditional probabilities associating each node to its probable direct cause. A Bayesian network has a structure of a Directed Acyclic Graph (DAG), which means that the arcs can not form cycles. They are unidirectional, so that, starting from any of the network nodes, it is impossible to return to the same node.

The first step in building a Bayesian network is related to identification variables of interest and then to represent them through the network nodes. Korb & Nicholson (2003) comment that this step is necessary to answer the questions: What nodes represent? And what values they can take? For discrete variables, the values of the variables must be mutually exclusive.

Some types of discrete nodes are:

- Boolean Nodes: These are propositions that assume binary values, ie true and false;

- Ordered Values: An example of this type of node is the variable consequence, because it can take values such as: low, medium and high.

The structure and topology of the Bayesian network should capture the qualitative relationship between variables. In particular, two node must be connected (if it is one purpose or the other causes) with an arc indicating the direction of effect. The only restriction on the existing Bayesian framework, as it was previously mentioned, is that it can not be cyclic.

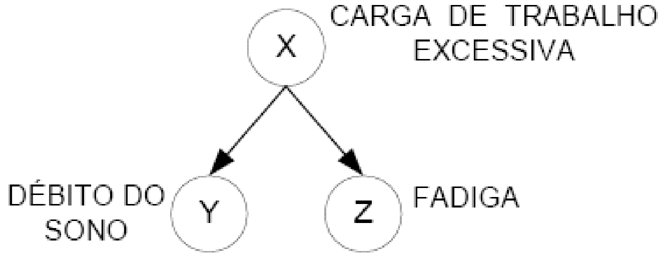
Mathematically, the Bayesian network is a pair n = {(V, E),P} where (V, E) is a directed graph representing nodes (or vertices) and edges (or arcs) respectively, and P is the distribution probabilities about V. Generally random variables V = {X1, X2, ..., Xn} are distributed to the nodes, while the arcs (E) represent the probabilistic causal relationship between nodes.

Once the network topology has been specified, the next step is to quantify the relationship between the connected nodes. This is done by assigning the probability distribution for each node, thus building a Conditional Probabilities Table (CPT). When it comes to discrete variables, each node is required to identify all possible combinations of their parent nodes. One must also identify the possible values which the variables can assume. Figure 80 shows a Bayesian network and CPTs of each variable. This network shows that the variable X (excessive workload) presents as consequences: the variables Y (Debit sleep) and Z (Fatigue), ie, a workload might have resulted in an insufficient sleep and fatigue. Each variable in the network takes on two possible values: T (True) and F (False). Therefore, the value 0.25, exposed in the 2nd row of the variable CPT associated Y represents the likelihood of a particular person to be sleep debt (Y) since it will not be under excessive workload (X).

The size of CPTs depends on the amount of parents who have each variable and the number of values it can take. Therefore, in the case of dichotomous variables, each node a network (Xi) has:

Number of elements of a CPT = 2^n, where n is the number of parents that have variable

Figure 80 shows that Y and Z have X as a parent. They are variables that take two values, T and F. Therefore Y and Z have 2 conditional probabilities and X has 1 conditional probability. However, considering the complement of each conditional probability, Y and Z have 4 conditional probabilities and X 2 conditional probabilities as show their CPTs



TPC de X	
P(X=T) = 0,40	P(X=F) = 0,60

TPC de Y		
X	P(Y=T/X)	P(Y=F/X)
T	0,80	0,20
F	0,25	0,75

TPC de Z		
X	P(Z=T/X)	P(Z=F/X)
T	0,80	0,20
F	0,30	0,70

Figure 80: **Bayesian network for the problem of excessive workload. Source:Menezes Droguett (2005)**

The degree of belief about the variables Y and Z is calculated by Bayes rule directly

Then, $P(Z=F)=(0,4)\ (0,2)+(0,6)\ (0,7)=0,50;$ (5.2)

and, $P(Y=F)=(0,4)\ (0,2)+(0,6)\ (0,75)=0,53$ (5.3)

One of the great features of Markov processes is the assumption of lack of memory. This means that if the current state of the process is known, are irrelevant information passed on inferences about their future states. This is the concept of Markov condition.

Recall that a directed graph is a pair (V, E), where V is a finite, nonempty set whose elements are called nodes (or vertices), and E is a set of ordered pairs of distinct elements of V. Elements of E are called edges (or arcs), and if (X,Y) ε E, we say that there is an edge from X to Y and that X and Y are each incident to the edge. If there is an edge from X to Y or from Y to X, we say X and Y are adjacent. Suppose we have a set of nodes $[X_1,X_2, ...X_k]$, where $k \geq 2$, such (X_{i-1},X_i) ε E for $2 \leq i \leq k$. We call the set of edges connecting the k nodes a path from X_1 to X_k. The nodes $X_2, . . .X_{k-1}$ are called interior nodes on path $[X_1,X_2, . . .X_k]$. The subpath of path $[X_1,X_2, . . .X_k]$ from X_i to X_j is the path $[X_i,X_{i+1}, . . .X_j]$ where $1 \leq i < j \leq k$. A directed cycle is a path from a node to itself. A simple path is a path containing no subpaths which are directed cycles. A directed graph G is called a directed acyclic graph (DAG) if it contains no directed cycles. Given a DAG G = (V, E) and nodes X and Y in V, Y is called a parent of X if there is an edge from Y to X, Y is called a descendent of X and X is called an ancestor of Y if there is a path from X to Y , and Y is called a nondescendent of X if Y is not a descendent of X. Note that in this text X is not considered a descendent of X because we require $k \geq 2$ in the definition of a path. Some texts say there is an empty path from X to X.

Assuming a network with three nodes as in Figure 81, where A probably cause B, B probably cause C, it can be said based on Markov condition, the probability of C | B is exactly the same probability of C | (B ∩ A), ie, knowing the fact that: A occurred, makes no difference in belief about C if we know that B has occurred. Then C is conditionally independent of A, since B occurred. Or, in probabilistic notation: {C} ind {A} | {B}.

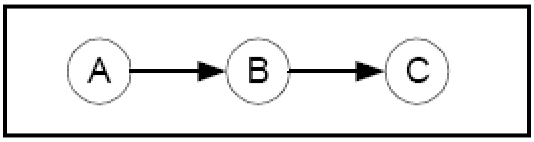


Figure 81:Serial conection. Source: Menezes & Droguett (2005)

Figure 82 shows that when two variables A and C have a common cause B, and there is no evidence of B, then the fact that one of the effects A is present, C for example, changes the probability of B occurs, which consequently also changes the the probability of the effect being present. However, if you already know about B, so the fact the effect is present C says nothing about the likelihood of also having the effect A. Then C is conditionally independent of A, since B occurred. Or, in probabilistic notation, {C} ind {A} | {B

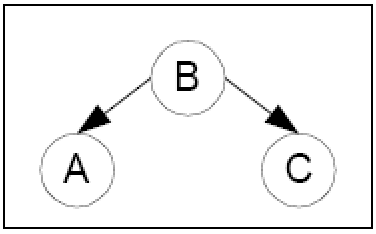


Figure 82: Conection type common cause. Source: Menezes, R. C. & Droguett, E. L. (2005)

Easily, one realizes that the pair N = {(V, E), P} satisfies the Markov condition according Arrifano & Oliveira (2004), then two variables are conditionally independent, given what is known about another variable that lies between the two variables in flow dependencies.

Figure 83 shows that A and C have a common effect B, i.e. A and C will probably cause B. In this case, parents are marginally independent, but the result of the common effect B, depends on both information. Once one knows the occurrence of B and that C is not explains the probable cause of B, the probability of C given B is conditionally dependent on A.

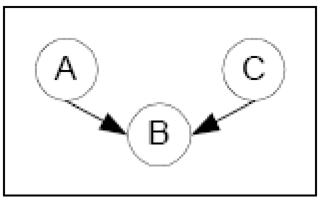


Figura 83: Conection type common effect. Source: Menezes & Droguett (2005)

In connection type common effect, the Markovian condition, is violated because the conditional independence shown in Figures 81 and 82 ceases to exist if it is known the value of a variable that is common effect of at least two variables not descended together. This phenomenon is well known as explaining away. A descended variable is a common effect of a set of variables not descended together when there exist paths between the variables in this set, and this variable.

The conditional independence in {C} ind {A} | {B} means that knowledge of B blocks, the relevance of A to C, or in the case of Figure 83, the lack of information about B blocks relevance of C to A . However, knowledge of B activates the relation between C and A. The term block means interrupting the flow of dependencies. These conditional independence, are properties of DAGs known as d-separation, where d refers to direction-dependent. The presence of d-separation is here denoted by ds. In the DAG of Figure 83, {C} ds {A} | {B}.

The probability distribution corresponding to the network, is calculated from the conditional probabilities, as shown in the equation below:

$$P(U) = P(X_1, X_2, ..., X_n) = \prod_{i=1}^{n} P(X_i \mid pa(X_i)) \qquad (5.4)$$

Where:

$P(U)$: joint probability for the network;

$P(X_i \setminus pa(X_i))$: conditional probabilities of X in relation to their parents.

Using the joint probability, we can get the posterior probabilities summing up for each outcome, the odds that a variable can take a network. Subsequently, normalize the probabilities obtained, thereby obtaining the posterior probabilities for each node or variable. It follows as an example, a process of inference network related shown in Figure 80. From CTPs X, Y and Z, one obtains the probabilities P (X, Y, Z) for each result. Therefore, according to the equation presented above, we have:

$$P(X, Y, Z) = P(X) \times P(Y \mid X) \times P(Z \mid X) \qquad (5.5)$$

Table 14 shows the calculation of joint probabilities. In these calculations, it is considered that the result T (True) is represented by number 0 and the result F (False) is represented by number 1.

Table 14: Joint probabilities related to the problem of excessive workload.

$P(x_0, y_0, z_0) = 0{,}256$	$P(x_0, y_1, z_0) = 0{,}064$	$P(x_1, y_0, z_0) = 0{,}045$	$P(x_1, y_1, z_0) = 0{,}135$
$P(x_0, y_0, z_1) = 0{,}064$	$P(x_0, y_1, z_1) = 0{,}016$	$P(x_1, y_0, z_1) = 0{,}105$	$P(x_1, y_1, z_1) = 0{,}315$

Assume now that node Y is observed as True ($Y = Y_0$), which is an evidence, meaning it has been found that a person experiences sleep debt. Then an inference process is performed to the nodes X and Z for calculating posterior probabilities of each outcome of these variables. From the joint probabilities of Table 14 and using the above equation, one obtains the posterior probabilities:

$$\{P(x_0 \mid y_0), P(x_1 \mid y_0), P(z_0 \mid y_0), P(z_1 \mid y_0)\} \text{ for } P(x_0 \mid y_0), \qquad (5.6)$$

for example, carried out the following calculation:

$$P(x_0 \mid y_0) = \frac{P(x_0, y_0, z_0) + P(x_0, y_0, z_1)}{P(x_0, y_0, z_0) + P(x_0, y_0, z_1) + P(x_1, y_0, z_0) + P(x_1, y_0, z_1)} \qquad (5.7)$$

It is observed that in the above equation the result y_1 for obvious reasons not appear in the calculations, since it is known that the result is y_0 of the variable. Table 15 shows the posterior probabilities pertaining to observation of the result y_0.

Table 15: Posterior probabilities for the problem of excessive workload.

$P(x_0) = 0.681$	$P(z_0) = 0.640$
$P(x_1) = 0.319$	$P(z_1) = 0.360$

Because the evidence on Y, the degrees of belief of the other variables were updated and one can conclude that once the sleep debt is present, the chances of having an excessive workload and fatigue are high.

The evidence previously mentioned, this is an empirical evidence or specific, as indeed was observed that ($Y = y_0$). However, other types of evidence can be used. This is called subjective because it reflects the uncertainty of an individual on the occurrence of a certain event. This uncertainty is evidenced by a tax. In the network shown in Figure 80, a subjective evidence could be, for example, a belief that a person has a ratio of two to one in favor of having sleep debt before further analysis, A = 0. Given this evidence, it can be said that P (A = 0 | Y) = β (2, 1) where β is a normalization factor. This implies that P (A = 0 | Y = 0) = 0.667 and P (A = 0 | Y = 1) = 0.333. Figure 84 shows the inclusion of A on this problem.

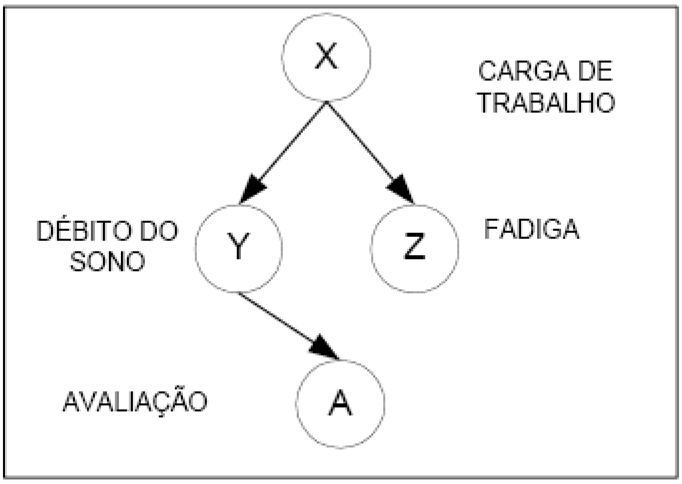


Figura 84: Inclusion of a subjective evidence in the Bayesian network of figure 15. Source: Menezes & Droguett (2005)

Since the evaluation result was favorable to sleep debt (A = 0), updating the conditional probabilities of the network is carried out as follows:

$$P(A=0) = P(A=0|Y=0)P(Y=0)+P(A=0|Y=1)P(Y=1) = (0,667)(0,53) + (0,333)(0,47) = 0,49$$

$$P(Y=0|A=0) = [(0,667)(0,47)]/0,49 = 0,64$$

$$P(Y=1|A=0) = [(0,333)(0,53)]/0,49 = 0,36$$

$$P(x \mid Y=0) = \frac{P(Y=0 \mid x)P(x)}{P(Y=0)} = (0{,}68;\ 0{,}32)$$

$$P(x \mid Y=1) = \frac{P(Y=1 \mid x)P(x)}{P(Y=1)} = (0{,}15;\ 0{,}85)$$

$$P(x \mid A=0) = \sum_{y} P(y \mid A=0)P(x \mid y)$$

$$P(X=0 \mid A=0) = [(0{,}64)\ (0{,}68) + (0{,}36)\ (0{,}15)] = 0{,}49$$

$$P(X=1 \mid A=0) = [(0{,}64)\ (0{,}32) + (0{,}36)\ (0{,}85)] = 0{,}51$$

$$P(z \mid A=0) = \sum_{x} P(x \mid A=0)P(z \setminus x)$$

$$P(Z=0 \mid A=0) = [(0{,}49)\ (0{,}80) + (0{,}51)\ (0{,}30)] = 0{,}545$$

$$P(Z=1 \mid A=0) = [(0{,}49)\ (0{,}20) + (0{,}51)\ (0{,}70)] = 0{,}455$$

6.3 Quantitative Applications using Bayesian Networks

There is great practical need to understand how human error manifests, how can it be explained, and how it can be predicted. However, to meet these questions, it is necessary to understand the relationship between its causes and effects. The effects are observed from the consequences of human error. The causes are explanations that have been found to what was observed. A retrospective analysis begins with the evaluation of effects and then seeks to identify the causes, i.e., the causes are described after the fact. In a prediction analysis, the causes are initiating events and the effects are possible results. Making a prediction means combining the causes and effects to anticipate probable errors. Manifestations (or effects) can be observed, while the causes can only be deduced after an introspection, i.e., by identifying characteristics of functional activity of cognitive and performance factors related to human contributing to the errors according to Hollnagel (1998).

The first and second generation of human reliability analysis is based on tools like fault trees. As a result, they can not satisfactorily model the existing causality in human action. These techniques of HRA for 1st and 2nd generation present disabilities making them not sufficiently effective and in need of an evolution to bring significant improvements in relation to human-system interface. Therefore, it is clear that to model the existing causality in human action has become a major challenge for HRA over the years and, consequently, it becomes necessary to develop a methodology for assessing human reliability. Given this context, modeling human actions by Bayesian Networks becomes an option to overcome the major shortcomings of traditional methods, providing greater flexibility to the variable components of a give system The following comments can be found in Chang & Mosleh (1999). The following are some of the expectations of these authors and how the use of Bayesian Networks can provide each of them:

1. Identification of errors in a contextual form and estimation of probabilities: Bayesian networks contextualize the error, qualitatively through graphical structure and quantitatively by calculating the conditional probabilities of the network;
2. Best causal models: Bayesian Networks are, by definition, graphical structures that represent the cause and effect relationships between variables;
3. More formal use of accumulated knowledge in the behavioral sciences: the conditional probability distributions can represent and quantify any knowledge;
4. More realistic representation of the dynamic nature of human-system interactions: since all the relations of cause and effect are relevant in the network and Bayesian expressed by conditional probabilities for each response of the system there is a corresponding set of conditional probabilities that express the behavior of worker. Likewise updates to the system's behavior under the action of the worker;
5. Able to be applied in different contexts: Bayesian networks are a great tool for analyzing different contexts. For example, monitoring operational problems through diagnostic and prognostic carried out effectively and efficiently and solve management problems through knowledge about factors relevant to the system;
6. Best calibration with current operational events: Bayesian networks can update the system by subjective inferences and empirical;
7. Consistency: the consistency of a Bayesian network represents any knowledge about a given system. Therefore, consistency for a particular process will be at least as satisfying as any other method;
8. Flexibility to represent new knowledge: the inclusion of a new issue on a given effect, for example, only changes the distribution of conditional probabilities of such an effect. On the other hand, changing a set of effects does not lead to any changes in its set of causes. This is also the case of exclusions;
9. Sensitivity to the variability of human behavior: using Bayesian networks it is possible to treat small deviations in the behavior of the worker, provided that they are represented in the network. In this case, it is important that the supervisor or person

who will monitor the system using Bayesian Networks is properly qualified and trained to capture the deviations from them and make updates to the system. It can be seen that the characteristics of Bayesian Networks seem to meet many of the expectations for future HRA methods, thereby demonstrating to be a good approach in modeling human errors.

In Menezes & Droguett (2005), the Bayesian inference seems more functional than empirical, because to infer about the “true value” of probability of human error empirically (frequentist statistic), it is necessary to find the “number of opportunities for error”. In general, making inferences about the “true value” of the probability of events in a subjective way presents advantages compared to the frequentist way, and if it is possible to use both is even better. Next, a Bayesian application using the proposed taxonomy and model presented in Chapter 4 will be presented.

As in section 5.1, the building of a database using the proposed taxonomy makes it possible to use classical statistics to find the more frequent human error failure mode. However, the building of this database is not easy and slow, so it is necessary to extract from expert opinion this knowledge and combine it with Bayesian statistics to make predictions. Many authors have proposed forms of eliciting the degree of believe from experts, but the method employed here was proposed by Nadler & Campello (2001) and applied to a power hydroelectrical process by Menezes & Droguetti (2005).

Observing the diagram in Figure 85 representing the model of error sequence process, one has the following variables: Berliner Process (X1); Domain (X2); Elementary Behavior (X3); Failure Mode (X4) and Error Type (X5) to build the Bayesian network. The variable Y will be used to represent the type of task selected.

According to the relationship of cause and effect, the follow Bayesian Network can be constructed (Figure 85):

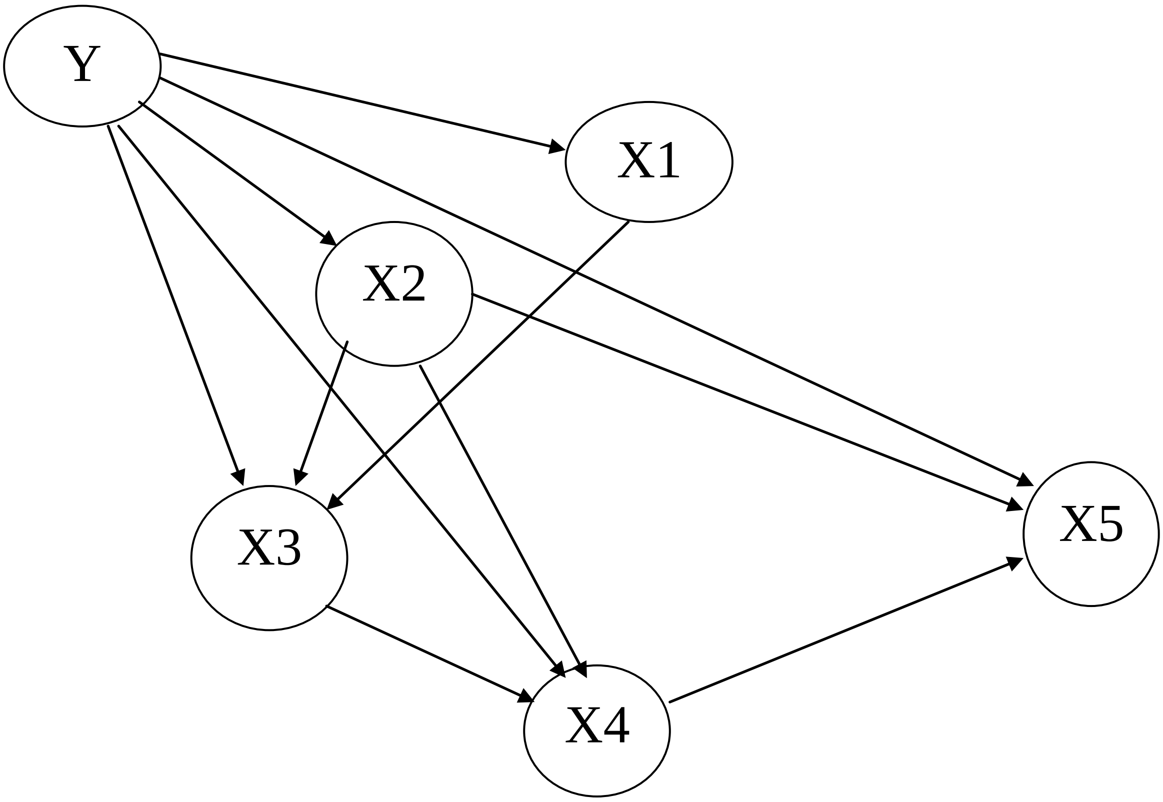


Figure 85: Bayesian network of a generic task

Analyzing this network:

- The task selected Y is the cause of virtually all others variables. Depending on the selected task all others variables can change their status;
- The Berliner process X1 is the cause of the elementary behavior X3;
- The domain X2 is the cause of the elementary behavior, the failure mode and the error type X5;
- The elementary behavior X3 is the cause of the failure mode X4;
- The failure mode X4 is the cause of the error type X5.

The categorization of Y depends on real cases considered by the analyst. Thus in this case, Y will be considered as a scenario. So, for a task Y, each variable X1 to X5 can assume the following values according to tables 16, 17, 18, 19, 20, 21 and 22 and Figure 86.

Table 16: Values assumed by variables

Node	Values
X1=Berliner Process	{cognitive; perceptive; motor; communication}
X2=Domain	{skill; rule; knowledge}
X3=Elementary behavior	{calculate choose; decide; compare; interpolate; verify; remember; inspect; observe; read; monitored; explorer; detected; identify; located; move; hold; push/pull; give; remove; discard; give back; position; adjust; typing; install; answer; inform; request; register; order; receive}
X4=failure mode	{ double capture slip; omission follow interruptions; reduced of intentionality; perceptual confusions; interference errors; omissions; repetitions; inversions; first exceptions; signs, countersigns, non signs; informational overload; rule strength; general rules; redundancy; rigidity; encoding deficiencies; action deficiencies; selectivity; workspace limitations; out of sight out of mind; confirmation bias; overconfidence; biased reviewing; illusory correlation; halo effect; problems of causality; problems with complexity; problems of diagnosis}
X5=error type	{slip; mistake}

Considering Y as a scenario and X5 as only a name of the human error it is possible simplify the Bayesian network as shown in Figure 86.

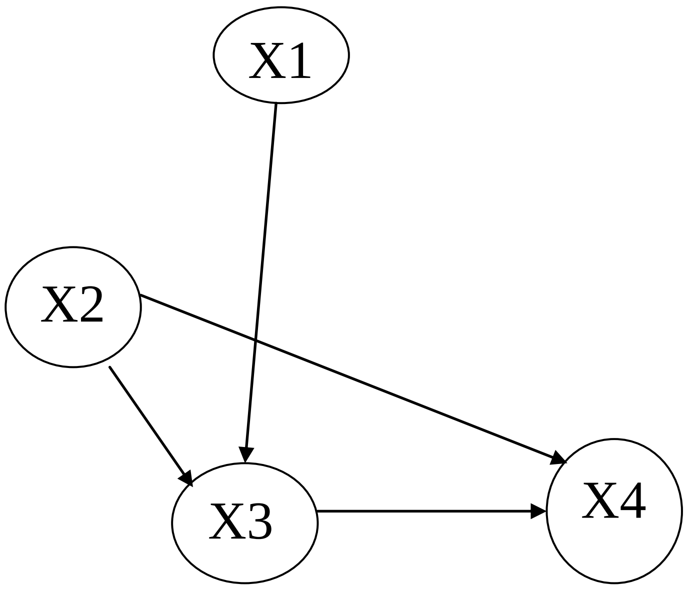


Figure 86: Bayesian network of the error

Analyzing this network:

- The elementary behavior X3 depends on the Berliner process X1;

- The domain X2 is the cause of elementary behavior X3 and failure mode X4;
- The elementary behavior X3 is the cause of failure mode X4.

Once the network topology is specified, the next step is to quantify the relationship between the connected nodes. This is done by assigning the probability distribution for each node, thus building a Conditional Probability Table (CTP). When it comes to discrete variables for each node, it is required to identify all possible combination of their parent nodes. It is also necessary to identify the possible values that the variables can take.

Considering the relationship of cause and effects shown in the network in Figure 86, and the values assumed by variables shown in Table 18, one can built the Conditional Probability Tables for each variable:

Let's assume that:

X1=Berliner process
Cognitive=1
Perceptive=2
Motor=3
Communication=4

X2=Domain
Skill=1
Rule=2
Knowledge=3

X3=Elementary Behavior
Calculate=1
Choose=2
Decide=3
Compare=4
Interpolate=5
Verify=6
Remember=7
Inspect=8
Observe=9
Read=10
Monitored=11
Explorer=12
Detected=13
Identify=14
Located=15
Move=16
Hold=17
Push/pull=18
Give=19
Remove=20
Discard=21

Give back=22
Position=23
Adjust=24
Typing=25
Install=26
Answer=27
Inform=28
Request=29
Register=30
Order=31
Receive=32

X4=Failure Mode
Double capture slip=1
Omission follow interruptions=2
Reduced of intentionality=3
Perceptual confusions=4
Interference errors=5
Omissions=6
Repetitions=7
Inversions=8
First exceptions=9
Sings, countersigns, non sings=10
Informational overload=11
Rule strength=12
General rules=13
Redundancy=14
Rigidity=15
Encoding deficiencies=16
Action deficiencies=17
Selectivity=18
Workspace limitations=19
Out of sight out of mind=20
Confirmation bias=21
Overconfidence=22
Biased reviewing=23
Illusory correlation=23
Halo effect=24
Problems of causality=25
Problems with complexity=26
Problems of diagnosis=27

Table 17: CTP X1

P(X1=1), P(X1=2), P(X1=3), P(X1=4)

X1	1	2	3	4
P(X1=x1)	p1	p2	p3	p4

Table 18: CTP X2

P(X2=1), P(X2=2), P(X2=3)

X2	1	2	3
P(X1=x1)	p1	p2	p3

Table 19: CTP X3

P(X3=X3 | X2, X1)

X1		1	1	1	2	2	2	3	3	3	4	4	4
X2		1	2	3	1	2	3	1	2	3	1	2	3
X3	1	p1	p2	p3	0	0	0	0	0	0	0	0	0
	2	p4	p5	p6	0	0	0	0	0	0	0	0	0
	3	p7	p8	p9	0	0	0	0	0	0	0	0	0
	4	p10	p11	p12	0	0	0	0	0	0	0	0	0
	5	p13	p14	p15	0	0	0	0	0	0	0	0	0
	6	p16	p17	p18	0	0	0	0	0	0	0	0	0
	7	p19	p20	p21	0	0	0	0	0	0	0	0	0
	8	0	0	0	p22	p23	p24	0	0	0	0	0	0
	9	0	0	0	p25	p26	p27	0	0	0	0	0	0
	10	0	0	0	p28	p29	p30	0	0	0	0	0	0
	11	0	0	0	p31	p32	p33	0	0	0	0	0	0
	12	0	0	0	p34	p35	p36	0	0	0	0	0	0
	13	0	0	0	p37	p38	p39	0	0	0	0	0	0
	14	0	0	0	p40	p41	p42	0	0	0	0	0	0
	15	0	0	0	p43	p44	p45	0	0	0	0	0	0
	16	0	0	0	0	0	0	p46	p47	p48	0	0	0
	17	0	0	0	0	0	0	p49	p50	p51	0	0	0
	18	0	0	0	0	0	0	p52	p53	p54	0	0	0
	19	0	0	0	0	0	0	p55	p56	p57	0	0	0
	20	0	0	0	0	0	0	p58	p59	p60	0	0	0
	21	0	0	0	0	0	0	p61	p62	p63	0	0	0
	22	0	0	0	0	0	0	p64	p65	p66	0	0	0
	23	0	0	0	0	0	0	p67	p68	p69	0	0	0
	24	0	0	0	0	0	0	p70	p71	p72	0	0	0
	25	0	0	0	0	0	0	p73	p74	p75	0	0	0
	26	0	0	0	0	0	0	p76	p77	p78	0	0	0
	27	0	0	0	0	0	0	0	0	0	p79	p80	p81
	28	0	0	0	0	0	0	0	0	0	p82	p83	p84
	29	0	0	0	0	0	0	0	0	0	p85	p86	p87
	30	0	0	0	0	0	0	0	0	0	p88	p89	p90
	31	0	0	0	0	0	0	0	0	0	p91	p92	p93
	32	0	0	0	0	0	0	0	0	0	p94	p95	p96

For better visualization the table the CTP of X4 will be divided into tree parts:

1. X2=1; X3; X4 <9 Considering that P(X4=X4>8 |X2=2, X3)=0; P(X4=X4>8 | X2=3, X3)=0

Table 20: CTP X4<9

P(X4=X4<9 | X2=1, X3)

		X4							
X2	X3	1	2	3	4	5	6	7	8
1	1	p1	p2	p3	p4	p5	p6	p7	p8
1	2	p9	p10	p11	p12	p13	p14	p15	p16
1	3	p17	p18	p19	p20	p21	p22	p23	p24
1	4	p25	p26	p27	p28	p29	p30	p31	p32
1	5	p33	p34	p35	p36	p37	p38	p39	p40
1	6	p41	p42	p43	p44	p45	p46	p47	p48
1	7	p49	p50	p51	p52	p53	p54	p55	p56
1	8	p57	p58	p59	p60	p61	p62	p63	p64
1	9	p65	p66	p67	p68	p69	p70	p71	p72
1	10	p73	p74	p75	p76	p77	p78	p79	p80
1	11	p81	p82	p83	p84	p85	p86	p87	p88
1	12	p89	p90	p91	p92	p93	p94	p95	p96
1	13	p97	p98	p99	p100	p101	p102	p103	p104
1	14	p105	p106	p107	p108	p109	p110	p111	p112
1	15	p113	p114	p115	p116	p117	p118	p119	p120
1	16	p121	p122	p123	p124	p125	p126	p127	p128
1	17	p129	p130	p131	p132	p133	p134	p135	p136
1	18	p137	p138	p139	p140	p141	p142	p143	p144
1	19	p145	p146	p147	p148	p149	p150	p151	p152
1	20	p153	p154	p155	p156	p157	p158	p159	p160
1	21	p161	p162	p163	p164	p165	p166	p167	p168
1	22	p169	p170	p171	p172	p173	p174	p175	p176
1	23	p177	p178	p179	p180	p181	p182	p183	p184
1	24	p185	p186	p187	p188	p189	p190	p191	p192
1	25	p193	p194	p195	p196	p197	p198	p199	p200
1	26	p201	p202	p203	p204	p205	p206	p207	p208
1	27	p209	p210	p211	p212	p213	p214	p215	p216
1	28	p217	p218	p219	p220	p221	p222	p223	p224
1	29	p225	p226	p227	p228	p229	p230	p231	p232
1	30	p233	p234	p235	p236	p237	p238	p239	p240
1	31	p241	p242	p243	p244	p245	p246	p247	p248
1	32	p249	p250	p251	p252	p253	p254	p255	p256

2. X2=2;X3; 8<X4<18 Considering that P(X4=8<X4>18 |X2=1, X3)=0; P(X4=8<X4>18 | X2=3, X3)=0

Table 21: CTP 8<X4<18

P(X4=8<X4<18 | X2=2, X3)

		X4								
X2	X3	9	10	11	12	13	14	15	16	17
2	1	p1	p2	p3	p4	p5	p6	p7	p8	p9
2	2	p10	p11	p12	p13	p14	p15	p16	p17	p18
2	3	p19	p20	p21	p22	p23	p24	p25	p26	p27
2	4	p28	p29	p30	p31	p33	p34	p35	p36	p37
2	5	p38	p39	p40	p41	p42	p43	p44	p45	p46
2	6	p47	p48	p49	p50	p51	p52	p53	p54	p55
2	7	p56	p57	p58	p59	p60	p61	p62	p63	p64
2	8	p65	p66	p67	p68	p69	p70	p71	p72	p73
2	9	p74	p75	p76	p77	p78	p79	p80	p81	p82
2	10	p83	p84	p85	p86	p87	p88	p89	p90	p91
2	11	p92	p93	p94	p95	p96	p97	p98	p99	p100
2	12	p101	p102	p103	p104	p105	p106	p107	p108	p109
2	13	p110	p111	p112	p113	p114	p115	p116	p117	p118
2	14	p119	p120	p121	p122	p123	p124	p125	p126	p127
2	15	p128	p129	p130	p131	p132	p133	p134	p135	p136
2	16	p137	p138	p139	p140	p141	p142	p143	p144	p145
2	17	p146	p147	p148	p149	p150	p151	p152	p153	p154
2	18	p155	p156	p157	p158	p159	p160	p161	p162	p163
2	19	p164	p165	p166	p167	p168	p169	p170	p171	p172
2	20	p173	p174	p175	p176	p177	p178	p179	p180	p181
2	21	p182	p183	p184	p185	p186	p187	p188	p189	p190
2	22	p191	p192	p193	p194	p195	p196	p197	p198	p199
2	23	p200	p201	p202	p203	p204	p205	p206	p207	p208
2	24	p209	p210	p211	p212	p213	p214	p215	p216	p217
2	25	p218	p219	p220	p221	p222	p223	p224	p225	p226
2	26	p227	p228	p229	p230	p231	p232	p233	p234	p235
2	27	p236	p237	p238	p239	p240	p241	p242	p243	p244
2	28	p245	p246	p247	p248	p249	p250	p251	p252	p253
2	29	p254	p255	p256	p257	p258	p259	p260	p261	p262
2	30	p263	p264	p265	p266	p267	p268	p269	p270	p271
2	31	p272	p273	p274	p275	p276	p277	p278	p279	p280
2	32	p281	p282	p283	p284	p285	p286	p287	p288	p289

3. X2=3;X3; X4>17 Considering that P(X4=X4>17 |X2=1, X3)=0; P(X4=X4>17 | X2=2, X3)=0

Table 22: CTP X4>17

P(X4=X4>17 | X2=3, X3)

		X4										
X2	X3	18	19	20	21	22	23	24	25	26	27	28
3	1	p1	p2	p3	p4	p5	p6	p7	p8	p9	p10	p11
3	2	p12	p13	p14	p15	p16	p17	p18	p19	p20	p21	p22
3	3	p23	p24	p25	p26	p27	p28	p29	p30	p31	p32	p33
3	4	p34	p35	p36	p37	p38	p39	p40	p41	p42	p43	p44
3	5	p45	p46	p47	p48	p49	p50	p51	p52	p53	p54	p55
3	6	p56	p57	p58	p59	p60	p61	p62	p63	p65	p66	p67
3	7	p68	p69	p70	p71	p72	p73	p74	p75	p76	p77	p78
3	8	p79	p80	p81	p82	p83	p84	p85	p86	p87	p88	p89
3	9	p90	p91	p92	p93	p94	p95	p96	p97	p98	p99	p100
3	10	p101	p102	p103	p104	p105	p106	p107	p108	p109	p110	p111
3	11	p112	p113	p114	p115	p116	p117	p118	p119	p120	p121	p122
3	12	p123	p124	p125	p126	p127	p128	p129	p130	p131	p132	p133
3	13	p134	p135	p136	p137	p138	p139	p140	p141	p142	p143	p144
3	14	p145	p146	p147	p148	p149	p150	p151	p152	p153	p154	p155
3	15	p156	p157	p158	p159	p160	p161	p162	p163	p164	p165	p166
3	16	p167	p168	p169	p170	p171	p172	p173	p174	p175	p176	p177
3	17	p178	p179	p180	p181	p182	p183	p184	p185	p186	p187	p188
3	18	p189	p190	p191	p192	p193	p194	p195	p196	p197	p198	p199
3	19	p200	p201	p202	p203	p204	p205	p206	p207	p208	p209	p210
3	20	p211	p212	p213	p214	p215	p216	p217	p218	p219	p220	p221
3	21	p222	p223	p224	p225	p226	p227	p228	p229	p230	p231	p232
3	22	p233	p234	p235	p236	p237	p238	p239	p240	p241	p242	p243
3	23	p244	p245	p246	p247	p248	p249	p250	p251	p252	p253	p254
3	24	p255	p256	p257	p258	p259	p260	p261	p262	p263	p264	p265
3	25	p267	p268	p269	p270	p271	p272	p273	p274	p275	p276	p277
3	26	p278	p279	p280	p281	p282	p283	p284	p285	p286	p287	p288
3	27	p289	p290	p291	p292	p293	p294	p295	p296	p297	p298	p299
3	28	p300	p301	p302	p303	p304	p305	p306	p307	p308	p309	p310
3	29	p311	p312	p313	p314	p315	p316	p317	p318	p319	p320	p321
3	30	p322	p323	p324	p325	p326	p327	p328	p329	p330	p331	p332
3	31	p333	p334	p335	p336	p337	p338	p339	p340	p341	p342	p343
3	32	p344	p345	p346	p347	p348	p349	p350	p351	p352	p353	p354

All probabilities here described need to be estimated. A database with these frequencies could be the best form to get this information. But the lack of a database with this information turns it almost impossible to get these frequencies. A study as the done in Section 5.1 is an adequate starting point to obtain this information. Note however, that a long time will be necessary to build this database. Therefore, opinion expert elicitation is another form to get this information. As was previously mentioned, there are many difficulties to perform an elicitation, but this approach could be an adequate solution while the database is in the implementation process. At the end of this process, the Bayesian network is ready to generate a posterior distribution in the presence of empirical evidence, subjective or both. This provides great flexibility to the analyst because it is possible to verify the likelihood of human error during the execution of a task through the observation made on the state of the worker.

6.4 Example of Application

As it can be seen, in tables 17,18,19,20,21 and 22, there is a lot of condicional probabilities that have to be found. As it does not exist a data bank with enough data to be processed, the elicitation of the opinion of experts is one way to get this data. However, it is a complex task. First, the amount of estimation is very difficult to get and, to find experts in the process under investigation with availability within companies to be elicitated, turns the task so really to be realized. In order to be able to contemplate this proposed taxonomy and model, a toy model, simplifies the developed one. This toy model was based on a real case colected from a Brazilian hydroelectric power company presented in Annex 4, and the expert used to perform the elicitation was the author of this thesis, expert with more than 30 years working for this company and the area of interest.

For this toy model, the **Report error n.083** (see Annex 8) was chosen.

Report error n. 083 September, 16 2004, load interrupted 70,00MW.

Summarized description: The accidental shutdown of circuit breakers 14G2 and 13T2 has as root cause the failure to identify the sources of which one was defective and unduly control pushbutton reset from another source that presented itself to normal operation.

The detailed analysis of this event revealed that:

1. The maintenance team was called because a circuit breaker was not working;
2. There is a written rule to identify a faulty breaker;
3. The worker chose the correct rule;
4. The worker failured to choose the faulty breaker;
5. The worker shutdown the wrong breaker.

Comments:

- The worker was an expert and had correctly performed this kind of task several times;
- The worker chose a written rule;

- The worker chose the correct rule but performed it wrongly;
- The worker was on domain of skill-based and committed a slip, according to Figure 14; (start task; There is a rule known to perform the task? Yes; Worker chooses the rule? Yes; Worker chooses the right rule? Yes; Worker performed the rule correctly? No; Skill-based Failure mode).
- In order to solve a problem and to make a decision, the worker wrongly chooses after considering many options. This is a pair of Berliner process: cognitive process and the elementary behavior: choose;
- The worker performed the task without paying due attention to what he was doing. This failure mode is: perceptual confusions**.**

Figure 87 shows the taxonomy and model to RDFH n.083.

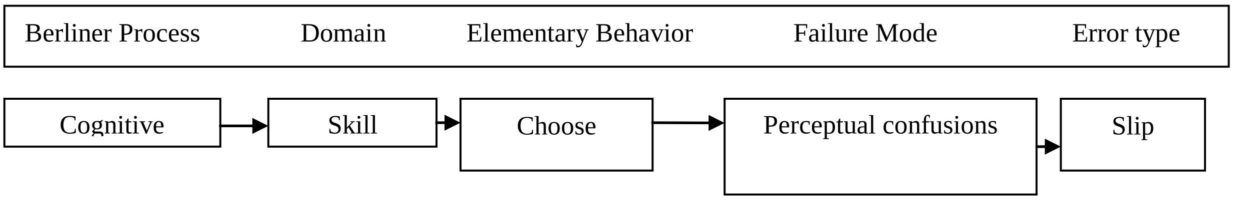


Figure 87: Sequence of error process RDFH n.083

The operator used the Cognitive process that is: *to* solve problems and to make a decision, to choose the faulty breaker, he perceived that there was written rule and he chose the correct rule but he performed the correct rule wrongly soon he was under the domain of skill-based to perform the task. When the worker cognitively decided to perform the task, he committed a failure mode named perceptual confusions that is: operators perform tasks without paying due attention to what they are doing and committed a slip and the task was performed without success.

For this toy model, the relationship of cause and effects shown in Bayesian network in Figure 88 will be considered. To build the corresponding CTPs, some assumptions in order to simplify the elicitation process will be assumed. Let's assume that:

- The Berliner Process was not elicitated, frequency data from descritive statistic colected in Chapter 4 was used;
- The Domain was not elicitated, frequency data from descritive statistic colected in Chapter 4 was used;

- The Elementary Behavior was elicitated, but as shown in Figure 28 , the frequency of more than 75% of elementary behavior were: Identify, Compare, Move, Remember, Decide, Remove, and the others elementary behavior named: Others.
- The Failure Mode was elicited, but as shown in Figure 29 , the frequency of more than 74% of failure mode were: Perceptual Confusions, Biased Reviewing, Encoding Deficiencies, Omission, and the others failure mode named: Others.

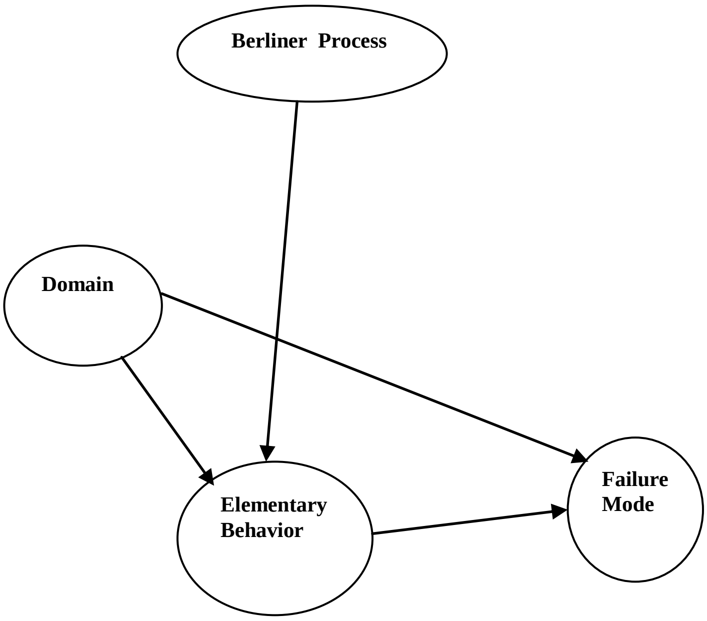


Figure 88- Bayesian network for toy model

Assuming that:

Berliner Process (X1): Cognitive=1; Perceptive=2; Motor=3; and Communication=4

Domain (X2): Skill=1; Rule=2; Knowledge=3

Elementary Behavior (X3): Identify=1; Compare=2; Move=3; Remember=4; Decide=5; Remove=6; Others=7

Failure Mode (X4): Perceptual Confusions=1; Biased Reviewing=2; Encoding Deficiencies=3; Omission=4; Others=5

The following tables are built

Table 23- Berliner Process

X1	Cognitive	Perceptive	Motor	Communication
Frequency X1	**0,33**	**0,33**	**0,33**	**0,01**

Table 24 – Domain

X2	Skill	Rule	Knowledge
Frequency X2	**0,52**	**0,24**	**0,24**

Table 25 – CTP Elementary Behavior

P(X3=X3 ˡ X2,X1)

X1	X2	X3 – Elementary Behavior						
		1	2	3	4	5	6	7
1	1	0	0,6	0	0,2	0,1	0	0,1
1	2	0	0,3	0	0,3	0,3	0	0,1
1	3	0	0,35	0	0,3	0,3	0	0,05
2	1	1	0	0	0	0	0	0
2	2	1	0	0	0	0	0	0
2	3	1	0	0	0	0	0	0
3	1	0	0	0,8	0	0	0,1	0,1
3	2	0	0	0,7	0	0	0,2	0,1
3	3	0	0	0,8	0	0	0,1	0,1
4	1	0	0	0	0	0	0	1
4	2	0	0	0	0	0	0	1
4	3	0	0	0	0	0	0	1

Table 26 – CTP X4 – Failure Mode

P(X4=X4 | X2, X3)

X2	X3	X4 – Failure Mode				
		1	2	3	4	5
1	1	0,4	0	0	0,4	0,2
1	2	0,5	0	0	0,45	0,05
1	3	0,4	0	0	0,5	0,1
1	4	0,8	0	0	0,1	0,1
1	5	0,7	0	0	0,2	0,1
1	6	0,5	0	0	0,5	0
1	7	0,3	0	0	0,3	0,4
2	1	0	0	0,9	0	0,1
2	2	0	0	0,9	0	0,1
2	3	0	0	0,9	0	0,1
2	4	0	0	0,9	0	0,1
2	5	0	0	0,9	0	0,1
2	6	0	0	0,9	0	0,1
2	7	0	0	0,5	0	0,5
3	1	0	0,9	0	0	0,1
3	2	0	0,9	0	0	0,1
3	3	0	0,9	0	0	0,1
3	4	0	0,9	0	0	0,1
3	5	0	0,9	0	0	0,1
3	6	0	0,9	0	0	0,1
3	7	0	0,5	0	0	0,5

In Tables 25 and 26, the condicional probabilities were estimated by Eng Gilberto Duarte, considering the case shown in **Report error n.083.**

Using E&P Office 3 shown in Figure 89, tables data 23,24,25,and 26 were processed.

Figure 89 – E&P Office 3

As a result of the simulation, the following analysis can be done:

The Failure Mode is the most difficult form to characterize the error and the most difficult form to analyze the worker behavior when he/she is erring. Knowing the probability distributions of the failure modes, actions can be taken to minimize the error or maybe the undesirable outcome. Considering the example of the toy model, the worker commited an accidental shutdown of circuit breakers.

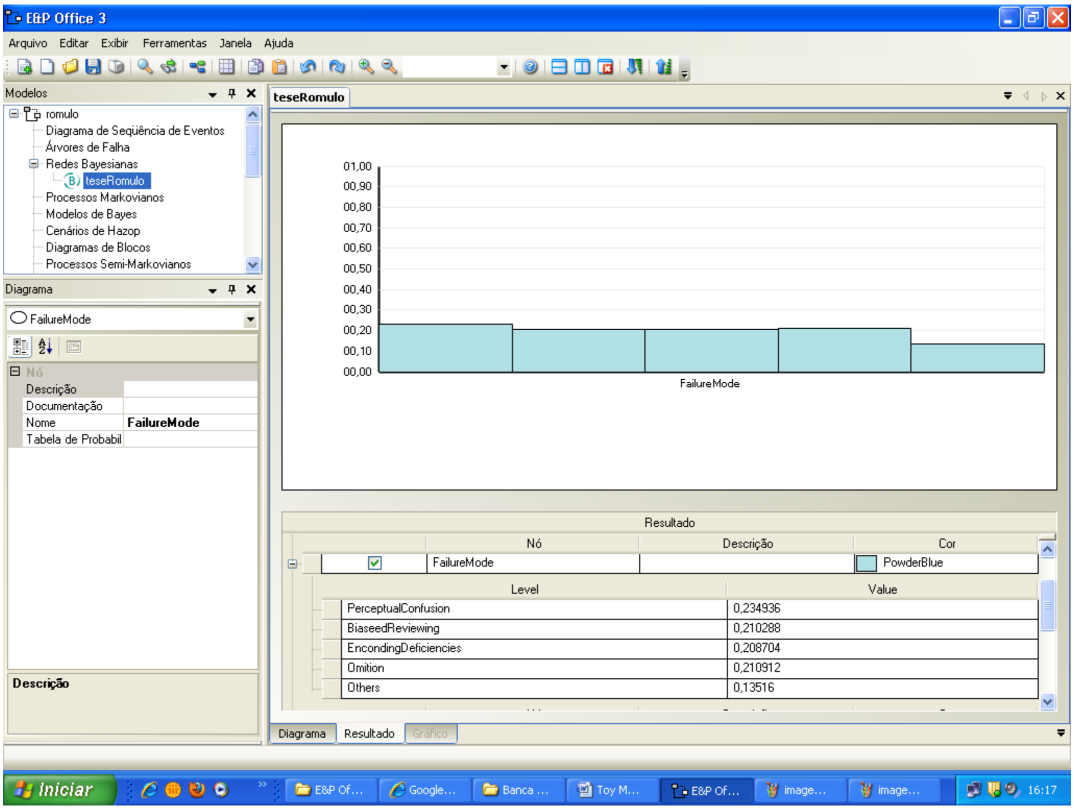


Figure 90 – Simulation – Failure Mode.

Considering the performed conditions and the expert opinion, the result shown in Figure 90 describes a probability distribution for the failure modes: Perceptual Confusions (23,5%); Omission (21%) and Biased Reviewing (21%).

Perceptual Confusion (Operator perform tasks without paying due attention to what they are doing) , represents a clear attention deficit. From this distribution one can take preventive actions in similar activities in the future, thus creating a scenario for reduction of human errors.

Considering the performed conditions and the opinion of the expert, the result shown in Figure 91 describe a probability distribution for the the Elementary Behavior: Identify (33%) and Move (25,6%).

Identify (to acknowledge the nature or indication of an object, according its implicit or predetermined characteristics). A training program that helps workers to better identify the most important objects in a substation can reduce human errors. A review of the identification codes and signaling could also help operators.

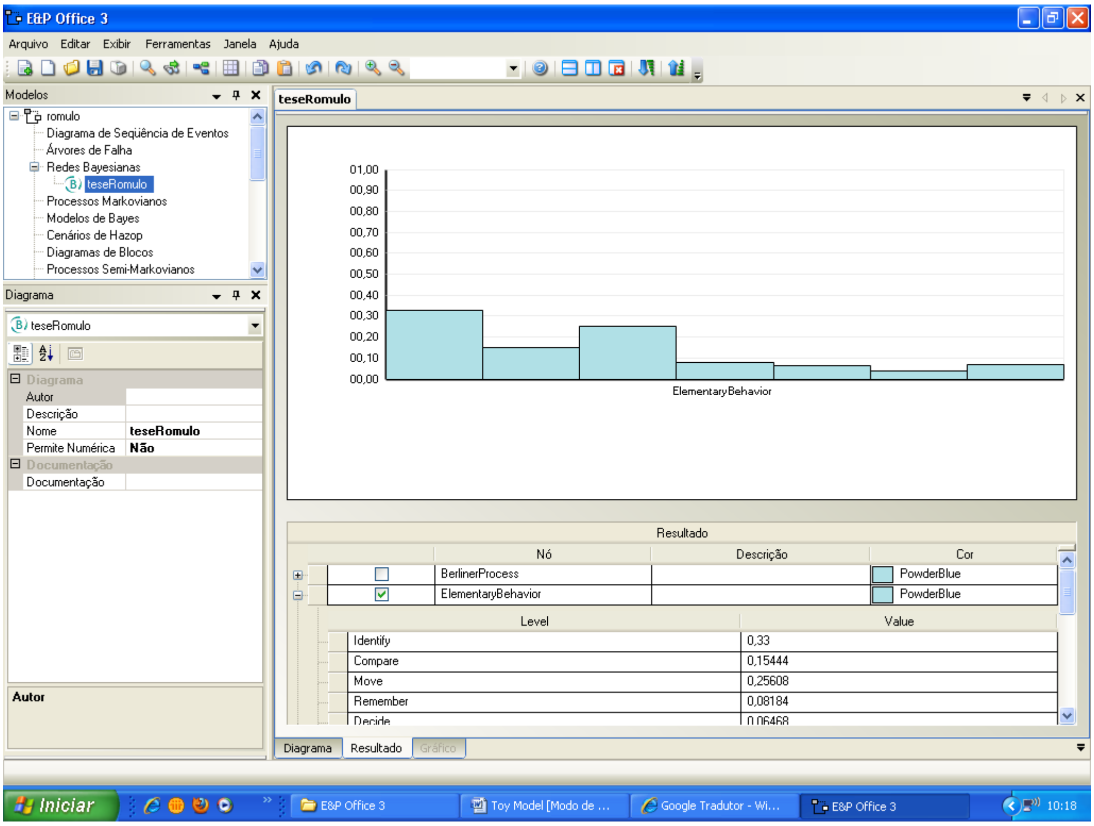


Figure 91 – Simulation – Elementary Behavior

If the Elementary Behavior identify is taken as evidence**,** and Berliner process **c**ognitive is taken as evidence**,** the result shown in Figure 91 presents failure mode: encoding deficiences with 90%.

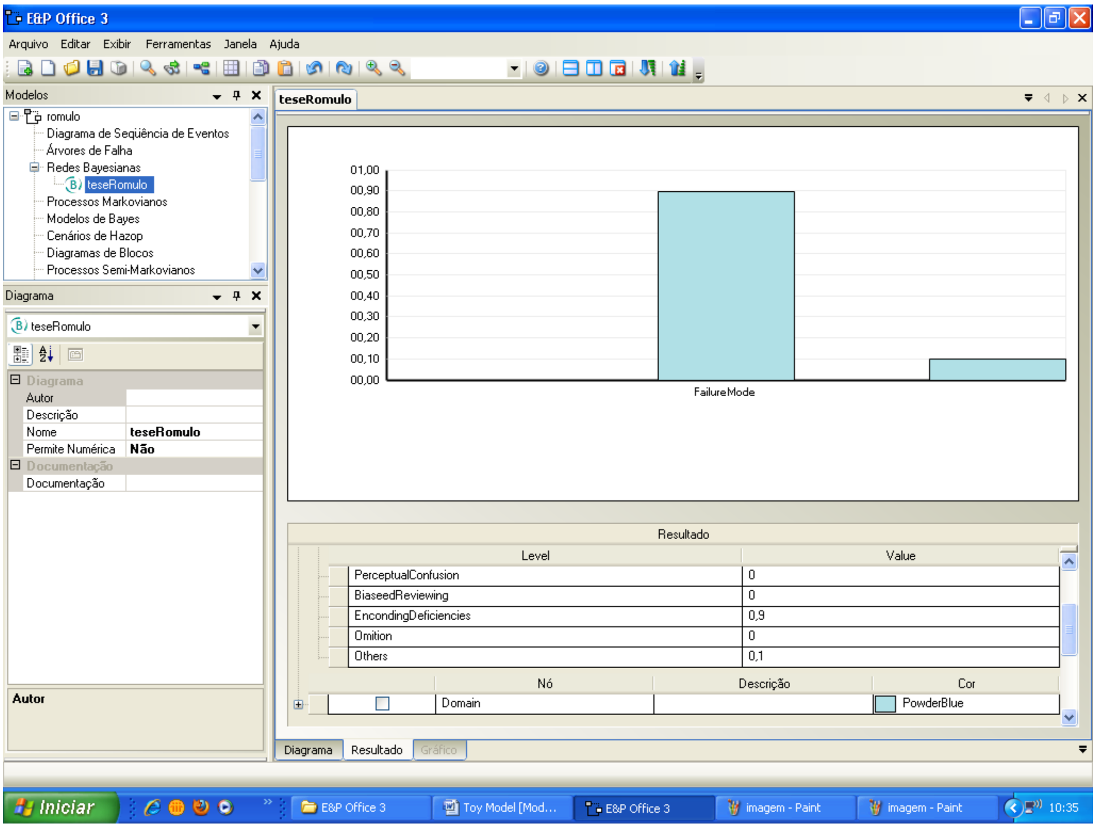


Figure 91 – Simulation with Evidence

From this model, and using a Bayesian network, it is possible to perform various analysis and to build a program for prevention of human errors in hydroelectric power companies.

7. CONCLUSIONS

This chapter presents a final discussion about the importance of taxonomy, model and application using BBN-Based methodology to analyze the human error in power hydroelectric systems. It also presents some difficulties on building a significant and robust database in order to help the development of policies for reducing the impact of human error on power hydroelectric companies. It finally presents some suggestions for future research.

This thesis presented a new taxonomy to classify human errors using the concepts proposed by Rasmussen and Reason and the classification to elementary behavior proposed by Berlinner. The combination of these concepts lead to a new taxonomy that classifies the human error of the worker when he/she is performing intervention (operator/maintenance) in the context of hydroelectric power systems. (See Figure 10). This more comprehensive classification allows the analyst to build a table with the human error description and classification of a set of occurrences collected in the field about interventions (operaton/maintenance) on hydroelectric power system that resulted in shutdown (blackout) caused by human error. This new taxonomy does not use Performance Shaping Factors (PSFs) because in hydroelectric power companies, data about the influence of PSFs on human error generally are scarce and mostly non-existent.

The analysis of 605 reported cases of human error over a period of ten years, indicated that the proposed taxonomy successfully translates the information in a standardized way of human error in the context of the Brazilian hydroelectric power industry. All these analyzes, the data collected and the database, are presented in Annex 8 and Annex 9. From the database built based on the proposed taxonomy (Annex 8), it was possible to present descriptive statistics in Chapter 5 where it was presented through tables and graphs with comments and examples, trends, frequency, seasonality and contingencies.

However, only the proposed taxonomy was not sufficient to show the sequence of mental events and relations of cause and effect that can lead a worker to commit human error. Therefore, it was presented a model based on the proposed taxonomy that shows the sequence of mental choice and the relations of cause and effect. (See Figure 13 and 14).

In Chapter 6, it was developed a BBN-based methodology with the goal of applying the proposed taxonomy and model to quantify the human error in the context of the hydroelectric power industry. A Bayesian network with relations of cause and effect using the variables porposed in taxonomy and model (See Figure 74) was developed. Conditional Probability Tables CTP (See Tables 10, 11, 12, 13, 14,15), were constructed for the Bayesian Network.

Through some simplifications, data using descriptive statistics presented in Chapter 5 and an expert elicitation for construction of CTPs, it was designed an example of application using the proposed Bayesian Network model. Through the E & P software Office 3, some analyzes were performed with quantification of human error in the context of the Brazilian company under consideration.

The work proposed in this thesis presents limitations so that further research is needed. The taxonomy needs simplification to be adapted and be feasible to applications by persons with expertise in electrical systems and in the same time expert in human reliability. Much training is required to prepare an analyst with conditions to apply this taxonomy. The taxonomy is somewhat complex to be applied. The elementary behavior has many options with overlapping boundaries, the failure mode is complex to choose from and also with overlapping boundaries. The analysis of RDFH is difficult to perform because of its overly technical language and with many subjective questions. It is so difficult to extract the root cause of human error from RDFH. It is difficult to decide in what step the error really occurred, because it’s necessary to realize what the worker was thinking in the exact moment when his action was deviated and the action was performed without success.

The models have an unclear union between the Berliner process and the failure mode. It is necessary to spend more time to fit this question. This union it is essential to understand the behavior of the worker in hydroelectric power system. The cognitive union of this variable must be better defined in the model.

It is mandatory to start the building of the database proposed in this thesis. From this database, many questions that were posted in this work could be answered. Through data analysis, it will be possible to reduce the overlay of boundaries between variables and reduce the number of different types of failure mode for a specific company.

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9. ANNEX

ANNEX 1 – **Human Error Report – RDFH/DMS 01/09**

1- SUMÁRIO DA OCORRÊNCIA:

1.1 – Local: SE CCD

1.2 – Data / Hora: 02/08/2009 às 12h 07 min

1.3 – DESCRIÇÃO SUCINTA DA OCORRÊNCIA:

Após conclusão das atividades de substituição da bucha do transformador 04T1 da SE CCD, ocorrida em 02.08.2009, no período das 09 às 12:00, foi devolvido o equipamento à Operação, conforme previsto, sendo energizado às 12h 04 min.

Às 12 h 07 min, ocorreram os desarmes dos disjuntores 14W1 e 12M1, através da chave 86 T, motivado devoido a válvula de segurança do transformador 04T1 encontar-se atuada.

Às 12 h 12 min, após inspeção no equipamento, foi constatado a válvula que a segurança estava atuada.

Às 12 h 13 min foi normalizado a atuação da válvula, pela equipe do CORE/SPMS e informado à Operação para energização do transformador.

Às 12 h 15 min foram fechados os disjuntores 14W1 e 12M1, normalizando o suprimento da carga.

2 - FATOS E DADOS RELEVANTES

- A substituição da bucha do transformador 04T1 estava prevista no PT 2009, sendo programada e cancelada por duas vezes, anteriormente, devido às condições climáticas desfavoráveis.
- A programação para o mês de agosto de 2009 foi motivada pela previsão de aumento de carga a partir do mês de setembro de 2009, na barra de 69 kV, e conseqüente aumento de carga para o transformador 04T2, na ocasião do desligamento do transformador 04T1 para substituição da bucha.
- Havia vazamento de óleo pela referida bucha, acarretando a possibilidade de falha no equipamento.

3 - CARGAS INTERROMPIDAS

Cargas da barra de 69 kV: 9,96 MW, durante 8 minutos.

4 - ANÁLISES DE DESEMPENHO DAS EQUIPES

4.1 - Equipe de operação

As atividades de liberação do equipamento (04T1) ocorreram dentro do previsto, ou seja: aberto o disjuntor 12M1, aberto o disjuntor 14W1 e em seguida as chaves 34T1-8 e 32T1-8 e em seguida fechado o disjuntor 14W1, fecha o 12M1 e passa a chave CHT de proteção do 04T1 da posição operação para a posição manutenção. No retorno do equipamento foram realizadas as seguintes manobras: Aberto os disjuntores 14W1 e 12M1, fechadas as chaves 34T1-8 e 32T1-8, fecha os disjuntores 12M1 e 14W1 e em seguida operando a chave de proteção “ CHT” do trafo 04T1(item 5.16 – 12:07hs) contrariando o programa de manobras (PGM) do CROP, que previa o fechamento da referida chave de proteção do trafo 04T1 antes do fechamento do disjuntos 14W1/12M1 o que resultou abertura do disjuntor(item 5.16 – 12:07). A inversão da operação do item 5.17 (fechar disjuntor) antes do item 5.16(passar a chave CHT do 04T1 da posição “O” EM MANUTENÇÃO para a posição “1” EM OPERAÇÃO), poderia ter evitado a saída do trafo pois seria identificado a atuação da proteção, antes do retorno do equipamento pela sinalização na Sala de Comando.

4.2 - Equipes de Manutenção – CORE / SPMS

Para a troca e adequação de uma bucha de 230KV o CORE normalmente realiza em 6 horas com uma equipe de 5 pessoas. Em face de restrições operacionais da SE devido a sobrecarga no trafo 04T2 a atividade de troca/adequação da bucha foi programada para um tempo de 3 horas, reduzindo pela metade o tempo normalmente estabelecido pelo CORE. Como o tempo foi reduzido a metade do período previsto foi necessário incluir na atividade uma equipe dobrada, ou seja, em vez de 5, 10 pessoas. Considerando que foi dobrada quantidade de pessoas foi necessário subir na tampa superior do transformador, onde ficava a válvula de segurança. A quantidade demasiada de pessoas sobre o trafo pode ter contribuído para a atuação do micro-swicth da válvula de segurança. A condução do planejamento e a disponibilização de infra-estrutura de material e pessoal para atender os prazos previstos no cronograma teve desempenho satisfatório, tendo disponibilizado o equipamento dentro do prazo previsto para energização. Apesar do bom planejamento executivo (PEX), a supervisão poderia ter realizado um controle mais eficaz das pessoas que ficaram trabalhando na tampa do trafo e no final da montagem da bucha ter realizado uma avaliação mais detalhada das possíveis falhas/danos em componentes na parte superior do trafo. Se tal procedimento fosse realizado poderia ter evitado a ocorrência.

4.3 – Equipe de Proteção – SPCP

Não participou das atividades

5 – RECOMENDAÇÕES

Manutenção

DMS/DOMA

- Divulgar com todo sistema organizacional a ocorrência, para que fatos desta natureza não ocorram mais em nosso sistema organizacional – Seminário de falha e vidio conferencia (até 30/03/2010)

SPMS

- Instalar uma proteção mecânica na parte superior do compartimento que aloja micro-swicth da válvula de segurança, visando impedir a sua atuação através de pequenos choques mecânicos (até 30/10/2009).
- Incluir o PMP – Procedimento de Manutenção Padrão em Transformadores /Reatores e Reguladores para atividades desta natureza que ora só é utilizado em montagens e reparo de equipamento que envolve movimentação de óleo (item teste da proteção própria antes da devolução) – até (03/11/2009)

CORE

- Incluir o PMP – Procedimento de Manutenção Padrão em Transformadores /Reatores e Reguladores para atividades desta natureza que ora só é utilizado em montagens e reparo de equipamento que envolve movimentação de óleo (item teste da proteção própria antes da devolução) – Já atendido

CROP

- Modificar os RTMs dos trafos de CCD, bem como em outras instalações que existam esquemas de proteção similares, a necessidade do operador de sistema receber a confirmação do operador de instalação da manobra da chave CHT que ativação a proteção, antes que se autorize a energização do equipamento (até 30/10/2009);

SPOI

- Disseminar com a equipe de operadores de CCD a análise da ocorrência destacando os aspectos de urgência de manobras decorrentes de parcela variável versus riscos de erro humano (até 30/10/2009).
- Realizar treinamento de reciclagem do normativo de comunicação verbal com os Operadores de CCD (até 30/10/2009).

SPCP

- Modificar, tanto para o 04T1 quanto para o 04T2, a supervisão do quadro sinóptico para que sinalize as proteções atuadas de forma independente da posição da chave CHT (até 31/10/2009).

6 – CONCLUSÃO

A saída das cargas foram motivada pela atuação, da válvula de segurança que foi operada durante a realização das atividades da substituição da bucha, motivado pela grande presença de pessoas na tampa superior do transformador. Apesar da atuação do micro-swicth da válvula de segurança, caso não tivesse havido a inversão dos itens 5.17/5.18 pelo item 5.16 do programa de manobras(PGM), a Operação, poderia ter identificado a atuação da válvula e solicitado a correção das anomalias.

ELABORADO POR

Eng. XXXXXXXXXXXX

Eng. XXXXXXXX / CORE

Assist. Tec. XXXXXXXX / CORE.

ANNEX 2 – **Human Error Report - RDFH –GRP 04/04**

1. - SUMÁRIO DA OCORRÊNCIA:

1.1 – Local: SALA DE COMANDO DA USD.

1.2 – Data: 16/09/2004.

1.3 – Horário: 14:53h.

1.4 – DESCRIÇÃO SUCINTA DA OCORRÊNCIA:

- Desligamento automático dos disjuntores 14G2 da unidade geradora 01G2 USD, e 13T2 da LT 03C1 por Falha Humana, devido comando manual de “rearme” na fonte CC do Regulador de Tensão, quando equipe do SPEU realizava manutenção corretiva no referido circuito. O rearme foi comandado na tela frontal do conversor CC/CC de 250 V / 15 V, de fabricação Guardian, durante intervenção para normalizar sinalização “Falha Regulador de Tensão - Alarme Agrupado” no 01G2 USD. No momento do desligamento a unidade se encontrava com 70 MW.

2. – HISTÓRICO DETALHADO:

2.1 – CONFIGURAÇÃO DO SISTEMA ANTES DA OCORRÊNCIA:

- Unidade Geradora 01G2 USD, no sistema com 70 MW, alimentando os Serviços Auxiliares da USD e a SE - Zebu através da Linha 03C1.

2.2 - SEQÜÊNCIA DOS DESLIGAMENTOS E DA RECOMPOSIÇÃO:

- Dia 16/09/2004 - às 14:53h, houve abertura dos disjuntores 14G2 e 13T2, operando a chave de bloqueio 86 WL, sinalizando “Falha Regulador de Tensão”, pela desatuação do relé auxiliar d3 de supervisão de falha nas fontes CA e CC (fls. 18 do desenho do Regulador de Tensão), devido ao zeramento da saída do conversor de corrente contínua de 250V / 15V – a fonte AC/DC estava inoperante, e era a causa fundamental da anomalia.
- Dia 16/09/2004 às 15:02h, foi paralelado o gerador através do 14G2, e às 15:03h foi fechado o 13T2, colocando a LT 03C1, que alimenta a SE-Zebu, em carga.

2.3 – CARGAS INTERROMPIDAS:

- Houve interrupção do fornecimento de 70 MW, que era o carregamento da unidade geradora no instante do desligamento. Este fornecimento foi suprido por outros geradores XXXX, não trazendo perturbações para o sistema.

3. - FATOS E DADOS RELEVANTES

3.1 – CRONOLOGIA DAS AÇÕES:

- Dia 13/09/2004 – O trafo da unidade geradora 01G2 USD estava alimentado de retorno, para suprir os Serviços Auxiliares de 13,8 kV, quando o SPEU foi solicitado para desadequar a proteção de “3V0”, uma vez que aquela unidade deveria retornar ao sistema devido à indisponibilidade naquela data de unidades geradoras da UST e ULG. Quando do comando de fechamento do disjuntor de campo do 01G2 USD, pelo Operador, o mesmo não foi aceito. Foi verificado ainda pela operação, que o Regulador de Tensão estava sinalizando "Falha Regulador de Tensão – Alarme Agrupado". O SPEU voltou a ser acionado, e interviu a partir das 18:10h, utilizando como Planejamento Executivo, o PEX – 0194/04 e APP anexos, quando verificou que a fonte de 250 Vcc / + 15 Vcc estava com o led de cor verde apagado, indicando alguma anormalidade, e sua saída zerada. (Estes Reguladores possuem três fontes em paralelo, isoladas através de diodos separadores - uma delas a partir do 127 Vac com duas saídas, uma de + 15 e outra de – 15 Vcc, e outras duas fontes a partir de 250 Vcc com saídas de +15 e - 15Vcc. A fonte ac tem dois leds: um vermelho na saída positiva e outro verde na saída negativa, que permanecem acesos enquanto suas saídas estiverem normais. As fontes cc têm por sua vez, quatro leds: três vermelhos, que permanecem apagados em condições normais, e acendem quando ocorrer Subtensão na Entrada, Sobre-tensão na Saída, e o último, quando a fonte estiver em Sobrecarga, enquanto que o quarto led é de cor verde e permanece aceso enquanto o suprimento interno da fonte estiver Normal). Esta fonte defeituosa de 250 Vcc / + 15Vcc, foi substituída, sendo outra vez acionado o comando de fechamento do disjuntor de campo, mais uma vez sem sucesso. O disjuntor de campo foi então retirado do seu painel, recebeu manutenção interna, e quando comandado mais uma vez, aceitou fechamento sendo a unidade geradora excitada e retornando ao sistema às 23:10h.

- Dia 14/09/2004 – A unidade voltou a sinalizar "Falha Regulador de Tensão – Alarme Agrupado"
- Dia 16/09/2004 – Às 14:25h, o SPEU interviu na 01G2 USD para normalizar a sinalização do Regulador de Tensão, através da SI SPEU-0328/04 e Planejamento Executivo / PEX – 0197/04 e APP, anexos. Todos os leds das três fontes estavam em sua configuração normal. O responsável pela intervenção em lugar de medir a tensão logo nas saídas das fontes, efetuou a medição após os diodos separadores, não identificando, portanto qualquer anormalidade, uma vez que neste ponto a tensão medida será sempre a maior tensão entre as duas fontes em paralelo. Levado pela intervenção anterior, foi induzido a acreditar que a fonte substituída três dias antes tinha voltado a falhar, comandando erroneamente uma botoeira de "rearme" existente na parte frontal do conversor. Ocorreu nesta oportunidade que a falha era na fonte ac – que provoca o mesmo tipo de sinalização no Regulador. Este comando de "rearme" provoca um "reset" na saída da fonte, com isto, o Regulador de Tensão ficou temporariamente sem o + 15 Vcc, provocando o desligamento da unidade gerador às 14:53h.
- Dia 16/09/2004 às 15:02h, foi paralelado o gerador através do 14G2, e às 15:03h foi

fechado o 13T2, colocando a LT 03C1, que alimenta a SE-Zebu, em carga.

3.2 – OPERAÇÃO:

- Nada a registrar.

3.3 – MANUTENÇÃO:

- Foi elaborado o Planejamento Executivo, através da elaboração do PEX No. 0197/04, anexo, contemplando a identificação da intervenção, recursos humanos, análise e condições para a intervenção, infra-estrutura necessária e detalhamento da intervenção, bem como a Análise Preliminar de Perigo – APP, também anexa.

3.4 – CAPACITAÇÃO TÉCNICA:

- Capacitação técnica da equipe envolvida não se apresentou satisfatória, uma vez que a mesma não identificou que a fonte que apresentava defeito era a AC e não a CC, bem como, desconhecia o fato que o comando de “rearme” zera temporariamente a saída da fonte.

3.5 – NORMATIVO:

- Normas do órgão normativo atendidas.
- Não existência de Instrução de Manutenção dos Reguladores de Tensão recém instalados.

3.6 – EQUIPAMENTOS:

- Instrumentos de medição adequados à atividade.

3.7 – PROTEÇÃO:

- O esquema funcional de trip comportou-se com eficiência no comando de trip, uma vez que o Regulador de Tensão, ficou temporariamente sem fonte de corrente contínua para seu controle interno, após o comando de “rearme” da fonte.

3.8 – SISTEMA DE SUPERVISÃO:

- Tanto a supervisão do Regulador de Tensão quanto da unidade geradora sinalizaram de forma correta.

3.9 – PROJETO ELÉTRICO:

- A fonte CC/CC deveria apresentar a identificação que o comando de “rearme” zeraria a saída da fonte.

3.10 – LOGÍSTICA DE APOIO:

- Adequada.

3.11 – OUTROS APOIOS:

- Adequados.

4. – ANÁLISE:

4.1 – DESEMPENHO DA EQUIPE ENVOLVIDA:

4.1.1 – OPERAÇÃO:

- Nada a registrar.

4.1.2 – MANUTENÇÃO:

O Desempenho da equipe de Manutenção de Proteção envolvida não foi satisfatório, considerando que a mesma não identificou corretamente a fonte que apresentava o problema, bem como, desconhecia o fato que a saída da fonte zeraria ao receber tal comando.

4.2 – CAPACITAÇÃO TÉCNICA:

A equipe executante, composta por um Assistente Técnico D e um Assistente Técnico A, tem capacitação adequada para realização deste tipo de trabalho.

4.3 – PROTEÇÃO:

Os esquemas de proteção e controle solicitados na ocorrência tiveram um desempenho satisfatório.

4.4 – SISTEMA DE SUPERVISÃO:

Satisfatório, com exceção da falta de sinalização que o comando de rearme zeraria a saída da fonte.

4.5 – Logística DE APOIO:

A logística estava adequada.

4.6 – OUTROS APOIOS:

Os apoios necessários estavam adequados.

5. - DIAGRAMA DE CAUSA E EFEITO

6. – CLASSIFICAÇÃO DA FALHA HUMANA (Conforme NM-TC-PA-GE-005)

O desligamento foi considerado de natureza falha humana, com erro por engano, sem corte de carga, não associado a danos materiais nem a danos pessoais.

MEIO AMBIENTE

MÃO-DE-OBRA

Não identificação de qual das fontes era a defeituosa

MÉTODO

Inexistência de Instrução de Manutenção do Regulador de Tensão Falta de conhecimento que o comando

de “rearme” zerava a saída da fonte

EQUIPAMENTO

DESLIGAMENTO 01G2 USD E 13T2

Falta de identificação que o comando de “rearme” zerava a saída da fonte Falta de padronização de sinalização nas fontes

7. – PLANO DE AÇÃO PLANO DE AÇÃO: O QUE QUEM QUANDO COMO ONDE

8. – CONCLUSÃO:

- O desligamento acidental dos disjuntores 14G2 e 13T2 teve como causa fundamental a não identificação de qual das fontes era a defeituosa, e comandar indevidamente a botoeira de rearme de uma outra fonte que se apresentava com seu funcionamento normal.
- Embora a causa principal do desligamento esteja bem caracterizada como uma falha humana, faz-se necessário destacar que, precisamos sempre estar atualizando as Instrução de Manutenção, e os debates sobre as melhorias nos processos de manutenção, conforme colocado no plano de ação, constante neste relatório.

8.1 – RECOMENDAÇÕES PRINCIPAIS

- Elaborar instrução de manutenção para os Reguladores de Tensão recém instalados nas USU/D/T e UAS.
- Fixar identificação nestas fontes que o comando de “rearme” provoca o zeramento temporário da mesma.
- Divulgar esta informação com as equipes envolvidas na manutenção dos reguladores que possuem esta fonte.

9. – ELABORAÇÃO

- Engº xxxxxxx e Tec° xxxxxxxx.

10. – APROVAÇÃO

- Engº xxxxxxxxxxxxxxx

ANNEX 3 – **Human Error Report - RDFH –GRP 04/06**

1. - SUMÁRIO DA OCORRÊNCIA:

1.1 – Local: Sala de Comando da SE – Bom Nome.

1.2 – Data: 22/03/2006.

1.3 – Horário: 09:01h.

1.4 – DESCRIÇÃO SUCINTA DA OCORRÊNCIA:

- Desligamento automático por falha humana do Disjuntor 12T3, com conseqüente desligamento dos Serviços Auxiliares, Barramento de 13,8 kV, e da LT 02V2, durante trabalhos do SPCP para substituição da medição operacional do disjuntor 12T3.

2. – HISTÓRICO DETALHADO:

2.1 – CONFIGURAÇÃO DO SISTEMA ANTES DA OCORRÊNCIA:

- Disjuntor 12T3 fechado em carga, suprindo a LT 02V2, os Serviços Auxiliares e cargas da Celpe em 13,8 kV.

2.2 - SEQÜÊNCIA DO DESLIGAMENTO E DA RECOMPOSIÇÃO:

- Dia 22/03/2006 - Às 09:01 h, houve abertura automática do Disjuntor 12T3 da SE BNO, por atuação do Relé de Sobrecorrente com Restrição de Tensão, desenergizando a LT 02V2, Serviços Auxiliares e a Barra 01B1/BNO.
- Dia 22/03/2006 – às 09:04h, abertos 21Y1, 21Y2 e 21Y3 e 11T3 através de comando manual.
- Dia 22/03/2006 – às 09:05h, abertos 12V2 através de comando manual.
- Dia 22/03/2006 – às 09:07h, fechado 12T3 através de comando manual.
- Dia 22/03/2006 – às 09:07h, fechamento automático 21Y1, 21Y2, e 21Y3 sem tensão.
- Dia 22/03/2006 – às 09:12h, abertos 21Y1, 21Y2 e 21Y3 sem tensão por comando manual.
- Dia 22/03/2006 – às 09:13h, fechado 12V2, colocando a LT 02V2 em carga
- Dia 22/03/2006 – às 09:13h, fechado 11T3 energizando 01B1
- Dia 22/03/2006 – às 09:14h, fechado os 21Y1, 21Y2 e 21Y3 energizando as cargas de 13,8 kV da Celpe.

2.3 – CARGAS INTERROMPIDAS:

- 20 MW.

3. - FATOS E DADOS RELEVANTES

3.1 – CRONOLOGIA DAS AÇÕES:

- Foi programado através da SI-SPCP-0130/06, para o período de 21/03/06 ao dia 24/03/06, intervenção no painel PCC13 para substituição dos indicadores analógicos da medição operacional do 12T3 por um multimedidor digital. Este painel PCC13, é do comando e sinalização do 12V3 e 12D1, e medição operacional dos 12V3 e 12T3.

- Foi verificado que para esta substituição, diferentemente de outras substituições idênticas, não seria possível a utilização de fiação nova, e sim o aproveitamento da antiga. Para tal, se fez necessário o manuseio de canaletas plásticas para o dimensionamento do comprimento da fiação existente.
- Durante a retirada de uma tampa de canaleta neste painel PCC13, ocorreu toque não intencional com conseqüente abertura do disjuntor 52-1, que supre com tensão ac proveniente do TP da barra 02BP, os relés de Sobrecorrente com Restrição por Tensão dos Disjuntores 12V3 e 12T3.
- Ocorreu sinalização imediata no quadro anunciador: "Falta Tensão TP Circuito de Proteção 02V3" e, segundos após ocorreu atuação da proteção 51V abrindo o 12T3 – não ocorreu entrada automática do Grupo Gerador, o que provocou o religamento automático dos 21Y1, 21Y2, e 21Y3 quando do fechamento manual do 12T3 sem tensão. Neste momento, foi acionado manualmente o botão "liga" do disjuntor 52-1 com conseqüente normalização do circuito de alimentação proveniente do TP de barra de 69 kV.
- Houve a preocupação no início dos trabalhos com a identificação no painel dos dispositivos que provocam desligamento, mas não foi identificado o disjuntor 52-1 como de alto risco. Houve ainda a preocupação quanto aos pontos onde se coletaria a alimentação DC para suprir os multimedidores.

3.2 – OPERAÇÃO:

- Nada a registrar.

3.3 – MANUTENÇÃO:

- O Planejamento Executivo da Intervenção foi elaborado de forma satisfatória.

3.4 – CAPACITAÇÃO TÉCNICA:

- Capacitação técnica da equipe envolvida é adequada às atividades.

3.5 – NORMATIVO:

- Normas e instruções do órgão normativo atendidas.

3.6 – EQUIPAMENTOS:

- Instrumentos de utilizados são adequados aos trabalhos realizados.

3.7 – PROTEÇÃO:

- O esquema funcional de TRIP se comportou com eficiência na abertura do disjuntor 12T3, porém sem exposição de bandeirola. A atuação da proteção 51V foi confirmada através do SAGE.

3.8 – SISTEMA DE SUPERVISÃO:

- Adequada.

3.9 – PROJETO ELÉTRICO:

- Adequado.

3.10 – LOGÍSTICA DE APOIO:

- Adequada.

3.11 – OUTROS APOIOS:

- Nada a comentar.

4. – ANÁLISE:

4.1 – DESEMPENHO DA EQUIPE ENVOLVIDA:

4.1.1 – OPERAÇÃO:

- Nada a registrar.

4.1.2 – MANUTENÇÃO:

- O desempenho da equipe de Manutenção de Proteção envolvida não foi satisfatório, uma vez que a mesma cometeu um ato de distração ao provocar toque não intencional com conseqüente abertura do disjuntor 52-1 no painel da SE BNO.

4.2 – CAPACITAÇÃO TÉCNICA:

- A equipe do SPCP tem capacitação adequada para realização dos trabalhos, tendo inclusive, realizado trabalhos anteriores similares em outros disjuntores desta SE, sem apresentar falhas.

4.3 – PROTEÇÃO:

- O esquema funcional de TRIP comportou-se com eficiência na abertura do disjuntor 12T3.

4.4 – SISTEMA DE SUPERVISÃO:

- O anunciador deveria apresentar em sua descrição "Falta Tensão TP circuito de Proteção 02V3 **e 12T3**" em lugar de "Falta Tensão TP circuito de Proteção 02V3".

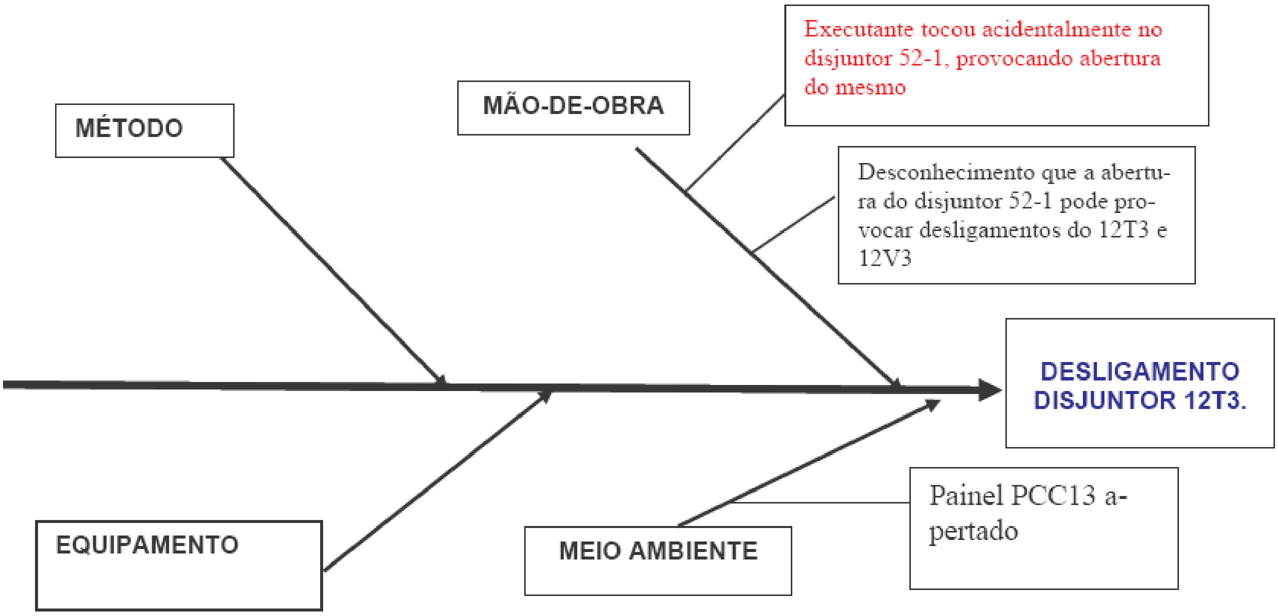
4.5 – LOGÍSTICA DE APOIO:

- A logística foi adequada.

4.6 – OUTROS APOIOS:

- Não existiu.

5. - DIAGRAMA DE CAUSA E EFEITO



6. – CLASSIFICAÇÃO DA FALHA HUMANA (Conforme NM-TC-PA-GE-005)

- Erro por Distração: embora houvesse a compreensão correta da situação e da intenção do objetivo a ser alcançado, foi produzida uma ação acidental com conseqüente desligamento do disjuntor 12T3 da SE BNO.

7. – PLANO DE AÇÃO

O QUE	QUEM	QUANDO	COMO	ONDE
Providenciar proteção "anti-bobeira" que evite o toque não intencional sobre o disjuntor 52-1.	SPCP	Abril/2006 (Atendido)	Colocando anteparo físico sobre o mesmo	SPCP
Providenciar identificação do risco de desligamento no corpo do disjuntor	SPCP	Abril/c006 (Atendido)	Com identificação adesiva no corpo do disjuntor	SE-BNO
Promover reunião de nivelamento da ocorrência	Todos	Maio/2006	Reunindo o Serviço para debater causas e efeitos da ocorrência.	SPCP
Complementar descrição na janela do quadro anunciador.	SPCP	Maio/2006	Alterando descrição	SE-BNO
Verificar causa não exposição bandeirola relé 51V	SPCP	Inspeção + Aguardar desenergização 12T3	Teste de atuação	SE-BNO

Identificar e sinalizar dispositivos de trip nos painéis das SEs que possam provocar desligamentos.	SPCP	PT 2007	Colando etiqueta in-dentificativa	SEs
Verificar causa não entrada automáti-ca do grupo gerador	SPMS	Maio/2006	Provocando partida e reciclando treinamento ao SPOI	SE - BNO

8. – CONCLUSÃO:

- O desligamento Acidental do disjuntor 12T3 da SE BNO teve como causa fundamental, o Erro por Distração (enquadrado na NM-TC-PA-GE-005) na execução da substituição dos indicadores analógicos por multimedidores digitais da SE BNO, quando ocorreu toque não intencional do disjuntor 52-1.

8.1 – RECOMENDACÕES PRINCIPAIS

- Quando houver atividades em painéis energizados com risco de desligamento e ou choque elétrico, deverá se fazer mapeamento e isolamento dos dispositivos que possam provocar desligamentos.
- Em toda intervenção do SPCP, deverá se manter o procedimento atual de se realizar um instante de concentração, fazendo-se um nivelamento “in loco” com todos os membros da equipe quanto aos trabalhos a serem realizados, riscos envolvidos, prazos a serem cumpridos, dificuldades a serem contornadas etc.

9. – ELABORAÇÃO

ANNEX 4 – Human Error Report - RDFH –GRL 06/99

1 – SUMÁRIO

1.1 - Local – SE STD

1.2 - Data e Hora – 25 / 11 / 99 - 11:32hs

1.3 - Descrições Sucintas da Ocorrência

Durante o processo de normalização do Disjuntor 12J2 da S/E STD, após manutenção preventiva, no dia 25/11/99 às 11h32minhs, por ocasião do retorno dos ajustes dos relés de sobre corrente, ocorreu o desarme do Disjuntor 12J2, atuando relé 51N, face abertura do circuito de corrente quando da mudança do tap do relé 51C, ocasionando a interrupção das cargas da Linha 02J2 - 4 MVA (STD/CUITÉ - SAELPA).

2 – HISTÓRICO DETALHADO

2.1 – CONFIGURAÇÃO DO SISTEMA ANTES DA PERTURBAÇÃO

A Subestação estava na sua configuração normal, com todos os Disjuntores de 138, 69 e 13.8 kV , fechados, exceto 13E1(Reator 03E1 desenergizado) e 12J2 substituído pelo 12D1.

2.2 – SEQUENCIA DOS DESLIGAMENTOS E DA RECOMPOSIÇÃO

11:00hs - SLMG devolveu o disjuntor 12J2

11:00/11:10hs - S/E STD efetuou inspeções, verificações, ativação alimentação VDC 12J2 e efetuou testes fechamento/abertura disjuntor 12J2

11:12hs - STD recebeu 12J2 livre para operação

11:15hs - CROL autorizou STD normalizar 12J2

11:22hs - STD fechou 32J2-4 e 32J2-5

11:23hs - STD fechou 12J2

11:24hs - STD abriu 12D1

11:25hs - STD colocou chave 43-12J2 na posição 12J2

11:28hs - STD abriu 32J2-6

11:28hs - STD fechou 32M1-8

11:32hs - STD retornou tap relés de sobre corrente de fase do 12J2 para o tap 4,0A abertura 12j2 com atuação relé 51n (acidental)

11:33hs - STD informou ocorrência ao CROL e recebeu autorização para normalizar 12J2

11:34hs - STD fechou 12J2 e informou ao CROL

2.3 – CARGAS INTERROMPIDAS

Houve interrupção de 4 MW durante 2 minutos.

3 - FATOS E DADOS RELEVANTES

3.1 – OPERAÇÃO

- O Operador envolvido na ocorrência, não utilizou a Instrução Interna existente na Instalação que discrimina todos os passos a serem seguidos no processo de mudança de ajuste de relés.
- O Operador não retirou o pente do relé nem tampouco sacou o relé da caixa.
- Imediatamente após o diagnóstico da ocorrência, o Operador interagiu com o CROL e procedeu a normalização do alimentador.

3.2 – CAPACITAÇÃO TÉCNICA

O operador envolvido na ocorrência tem 20 anos na função operador, dos quais 18 foram em Usina. Trata-se de um funcionário exemplar, de muita experiência, responsabilidade, compromisso e de um perfil técnico muito bom.

3.3 – NORMATIVO

A Instrução Interna existente na Instalação está devidamente atualizada e internalizada na equipe de Operadores.

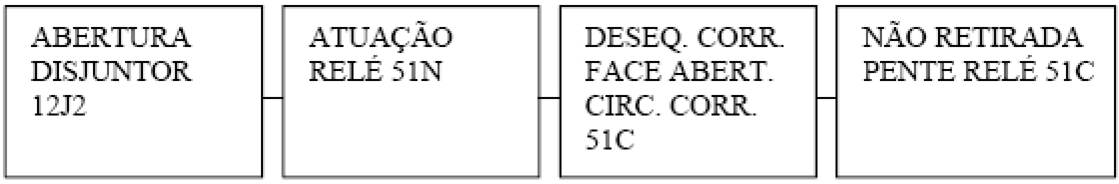
4 – ANÁLISE

4.1 – OPERAÇÃO

A tarefa de mudança de ajuste de relé é de alto risco, embora seja um procedimento já normatizado e de domínio dos operadores da S/E STD. Porém, por não ser realizada com freqüência, requer uma atenção especial por ocasião da necessidade de realizá-la. O fato ocorreu por ocasião da mudança de ajuste do último relé de fase (C), quando o operador esqueceu de retirar o pente do relé e face a abertura do circuito de corrente para mudança do tap, houve um desequilíbrio de corrente suficiente para operação do relé de neutro - 51N. De imediato, o operador constatou o erro e procedeu a informação ao CROL e a normalização da LT 02J2.

O operador mesmo conhecedor da Instrução de mudança de ajuste de relé existente na S/E STD, que enfatiza a necessidade da desativação do pente do relé e respectiva retirada do relé da caixa para executar a mudança do tap, não assim procedeu, e face a repetitividade das ações (relé 51A, depois 51B e por último 51C) culminou com o esquecimento da retirada do pente do relé e a conseqüente falha operacional. Após o diagnóstico da ocorrência, o procedimento do operador foi correto.

5- ARVORE DE CAUSA



6 – CLASSIFICAÇÃO DA FALHA

6.1 – TAREFA

6.1.1 – TIPO: Programado

6.1.2 – CLASSIFICAÇÃO: Simples, Rara, Programado, Normalização de equipamento/sistema

6.2 – AGRAVANTES DO RISCO

6.2.1 – AGRAVANTES DO RISCO: A tarefa é repetitiva e requer longos períodos inativos

6.2.2 – PESO: 1

6.2.3 – AGRAVAMENTO : 1,2

6.3 – FATORES DETERMINANTES DO DESEMPENHO HUMANO

6.3.1 – SITUACIONAIS : Ambiente: 1) – Localização; 2) – Ajuste de proteção; 3) – Acesso

6.3.2 – INDIVIDUAIS :

3.3.2.1 – HOMEM : 1) – Auto-confiança

3.3.2.2 – STRESSORES: 1) – Risco elevado

6.4 – DADOS COMPLEMENTARES:

6.4.1 – INTERVALO DE DESCANSO ANTES DO TURNO: 153.354 (12:00)

6.5 – QUANTIFICAÇÃO DO RISCO

3.5.1 – RISCO NOMINAL DE FALHA OPERACIONAL (RN): 0,018

3.5.2 – RISCO ESTIMADO: 30,0000%

6.6 – FALHA OPERACIONAL

6.6.1 – GRAU DE SEVERIDADE: Falha afetando o consumidor

6.6.2 – ERRO ESTIMADO: Erro Sequêncial

7 – PLANO DE AÇÃO

I-TEM	O QUE	QUEM		ONDE	QUAN-DO	POR QUE	COMO
		ORGÃO	RESP.				
1	Reciclar pro-cedimen-tos da II de mu-dança de a-juste de relé	SLOG	Praxedes	S/E STD	Nov/99 Realiza-do	Minimi-zar os riscos quando de mu-dan-ça dos ajus-tes de relé	Utilizan-do a II de mudan-ça de ajuste de relé e relé co-ringa
2	Enfatizar a importância do cumpri-mento rigoro-so da sequên-cia dos procedi-mentos da II	SLOG	Praxedes	S/E STD	Nov/99 Realiza-do	Consci-entizar Os Ope-Radores do fiel cumpri-mento da sequên-cia da II	Apresen-tando as ra-zões e conse-quên-cias de cada ação ou omissão

ANNEX 5 – Human Error Report - RDFH –GRO 02/09

1. SUMÁRIO DA OCORRÊNCIA

1.1. Local da Falha: SE ELISEU MARTINS
1.2. Equipamentos: Barra 02BP, Trafos 04T1, 04T2 , 02T5 e LT 02L2
1.3. Data: 25 / 08 /2009
1.4. Horário: 14:02 h

2. DESCRIÇÃO DA OCORRÊNCIA

Desligamento da Barra 02BP, Trafos 04T1, 04T2, 02T5 e LT 02L2, decorrente da abertura automática dos disjuntores 14T1, 14T2, 12T1, 12T2, 12T5 e 12L2 na SE/ELM, durante trabalhos desenvolvidos pela equipe de manutenção de proteção e controle do SOCP, pela equipe da DOMC e pela equipe da empresa ESC Engenharia, que estavam efetuando testes de validação da nova base de dados do SAGE, fim atender o projeto de teleassistência da SE/ELM.

O desligamento acidental ocorreu no momento em que o mantenedor efetuou a atuação do relé de bloqueio 86-T5, associado às proteções do Trafo 02T5, sendo que neste momento ocorreu a atuação do esquema de falha sem corrente do disjuntor 12T5, provocando o desligamento geral da Barra 02BP e dos Trafos 04T1, 04T2 e 02T5.

Após a ocorrência, a equipe de manutenção realizou análise detalhada, fim identificar a causa da atuação indevida do esquema de falha do disjuntor 12T5, constatando que o contato da chave 86-T5, que tem a função de ativar o bloqueio de comando do disjuntor 12T5 e predispor a liberação para reset da mesma, também tem a função de predispor o esquema de falha sem corrente do disjuntor 12T5. Como em princípio, o disjuntor 12T5 não abriu pela simples atuação da chave de bloqueio 86-T5, a lógica do esquema de falha deste disjuntor foi completada na simulação, provocando a sua atuação indevida.

3. CONFIGURAÇÃO DA SE ELISEU MARTINS ANTES DA OCORRÊNCIA

A configuração da SE Eliseu Martins antes da ocorrência, encontrava-se com a LT 04M2, Trafos 04T1, 04T2, 02T5 e LT 02L2 energizados, em condições normais de operação.

4. SEQUÊNCIA DO DESLIGAMENTO E DA RECOMPOSIÇÃO

14:02 h- Desligamento Automático, Indevido da LT 02L2, na realização da SI SOCP- 313/2009.
Desligamento Automático 04T1/04T2, indevido, face simulação de atuação da chave de bloqueio 86-T5, quando da realização da SI SOCP 313/2009, sinalizando 50BF associado ao 12T5, atuando relé de bloqueio 12T1, 12T2, 14T1, 4T2, 12T5 e 86.1 e 86.2 do 02A1.
14:14 h - Disponibilizados 04T1/04T2 ao ONS
14:17 h - 14T2 fechado
14:17 h - 12T2 Fechado energizando 02BP
14:17 h - 12L2 fechado energizando cargas 02L2 - ELM/EMT

14:18 h - 14T1 fechado
14:18 h - 12T1 fechado.
Cargas Interrompidas: 15,1 MW.
Obs:
14:06 h - Disponibilizado 04T1/04T2 ao ONS e posteriormente desconsiderado, face chaves de bloqueio atuadas só aceitarem reset após isolar 12T5.

5. CARGAS INTERROMPIDAS

Ocorreu o desligamento da LT 02L2 com a interrupção de 15,1 MW.

6. FATOS E DADOS RELEVANTES

- O objeto da intervenção que estava sendo realizada pelas equipes do SOCP, da DOMC e da empresa ESC Engenharia, era realizar os testes de validação da base de dados do SAGE, fim atender ao projeto de teleassistência da SE/ELM, sendo que no momento da ocorrência, estavam sendo realizados os testes de reset por telecomando da chave de bloqueio 86-T5;
- Foram realizados todos os planejamentos executivos, bem como o nivelamento com os participantes envolvidos, antes da realização dos testes;
- A equipe envolvida nos trabalhos já havia realizado as mesmas simulações nas chaves de bloqueio 86-04M2, 86-04T1, 86-04T2, 86-02A1, sem que tenha ocorrido anormalidades;
- A atuação da chave 86-T5 se fazia necessário, devido a lógica de reset requerer a informação de que a mesma esteja atuada, fim permitir a efetivação do comando de reset.
- Durante a ocorrência houve perda da telessupervisão da SE/ELM para o CROO, COOS e ONS, face perda momentânea da alimentação 220 VCA para o modem de comunicação.

7. ANÁLISE DO DESEMPENHO HUMANO

As equipes envolvidas na intervenção realizaram análise dos testes a serem realizados, no entanto, não foi visualizado o risco de atuação do esquema de falha do disjuntor 12T5, pelo fato de que o único contato normalmente aberto da chave 86-T5, utilizado no projeto de proteção e controle, não tem a função direta de desligamento do disjuntor 12T5.

8. BRAINSTORMING DO DESLIGAMENTO

- Concepção inadequada de projeto;
- Falta de análise detalhada do projeto;
- Aperfeiçoamento do trabalho em equipe;
- Necessidade de reciclagem nos sistemas digitais da SIEMENS;
- Ampliar conhecimentos e experiências com os sistemas digitais da SE/ELM;

- Necessidade de participação mais ativa do Serviço de Proteção nos comissionamentos;
- Necessidade de programação detalhada dos eventos em comissionamento;
- Falta de análise preventiva de sistemas de proteção, fim atender manutenções e implementação de melhorias;
- Falta de padronização entre as telas de nível 2 e nível 3 no SAGE;
- Melhorar capacitação das equipes de operação da Instalação e de Sistema para melhor entender a funcionalidade dos Sistemas Digitais em operação na SE/ELM;
- Normatização da operação das telas de nível 2 e 3 do SAGE.

9. DIAGRAMA DE CAUSA E EFEITO (vide anexo I)

10. CARACTERIZAÇÃO DA TAREFA EXECUTADA - IN-OP.01.007 (vide anexo II)

11. PLANO DE AÇÃO (vide anexo III)

12. DIAGRAMA UNIFILAR DA SE ELISEU MARTINS:

Vide endereço eletrônico da DOMO3

http://chesfnet/DO/Domo/HomePage/index.html

13. CONCLUSÃO:

O desligamento acidental da Barra 02BP, dos Trafos 04T1, 04T2, 02T5 e LT 02L2 da SE Eliseu Martins foi provocado pela atuação da chave de bloqueio 86-T5, que desencadeou a atuação do esquema de falha sem corrente do disjuntor 12T5, em decorrência de uma falta de análise detalhada do projeto de proteção e controle, por parte da equipe que estava executando os testes de validação da base de dados do SAGE, em virtude de uma concepção inadequada do referido projeto.

14. CLASSIFICAÇÃO DO ERRO HUMANO (NM-TC-PA-GE-005)

. **Tipo:** Erro por engano

. **Impactos:** DFH com corte de carga

. **Danos:** nenhum

15. . ELABORAÇÃO:

Data: 10 / 09 / 2009

ANNEX 6 – Human Error Report - RDFH –STC 01/05

1. SUMÁRIO

Desligamento automático do transformador 04T1 da Subestação de Santo Antônio de Jesu com o conseqüente desligamento da barra de 69 kV desta SE, coincidente com defeito trifási ao longo do alimentador 02J4, Santo Antônio de Jesus/Nazaré, devido a sensibilização proteção de sobrecorrente do transformador, provocando perda de carga de 66,13 MW.

2. HISTÓRICO DETALHADO

2.1. CONFIGURAÇÃO DO SISTEMA ANTES DA PERTURBAÇÃO

O Sistema Sul estava em configuração normal com todas as linhas de transmissão equipamentos disponíveis.

2.2. SEQÜÊNCIA DOS DESLIGAMENTOS/NORMALIZAÇÕES

Hora	Evento
20:08	Desarme da barra de 69kV STJ com abertura dos disj. 14T1,12J4,12J6 e 12T sem indicação de proteção. - 04T1/02A1- atuação chave de bloqueio; - Alívio de carga por subtensão; - LT 02j4 - proteção distância partida fase A,B,C,N; - Proteção distância partida geral
20:27	Fechado 14T1/STJ
20:28	Fechado 12J4/STJ
20:29	Fechado 12J6/STJ
20:29	Fechado 12T5

2.3. CARGAS INTERROMPIDAS

1) 02J4 – 46,20 MW e 02J6 – 19,93MW
2) 20:15/20:31 h – cargas da SE Milagres/Coelba transferidas para o regional de Irecê.
3) 20:24/20:31 h – cargas da SE Amargosa/Coelba transferidas para o regional de Irecê.

3. FATOS E DADOS RELEVANTES

3.1. ESTUDOS ELÉTRICOS

Face a configuração de operação da SE Santo Antônio de Jesus ser em derivação da 04F2-GVM/FNL, a segunda zona da proteção de distância do terminal 14F2 da Governador Mangabeira era sensível para defeitos entre fases no 69 kV da SE Sar Antônio de Jesus. Por este motivo, em 1997, foram definidos ajustes específicos para temporizações de segunda zona das LT´s 04F2, Governador Mangabeira/Santo Antôr de Jesus/Funil, no terminal de Governador Mangabeira e da LT Santo Antônio Jesus/Nazaré, 02J4, na SE Santo Antônio de Jesus, bem como reduzida a curva temporização da proteção de sobrecorrente do lado de 69 kV do trafo 04T1 da SE Sar Antônio de Jesus.

Em Fevereiro de 2001, após a colocação de pontos de geminamentos adicionais 02J4-Santo Antônio de Jesus/Nazaré, a COELBA solicitou em regime de urgênci virtude da realização do Carnaval e a SE Santo Antônio de Jesus atender à área d de Itaparica, que a CHESF elevasse a temporização da segunda zona da proteção LT, para melhorar a seletividade com as proteções das demais saídas de 69 kV Nazaré.

Para implantação do novo ajuste, foi verificada a seletividade com a proteção de se zona do terminal 04F2 da SE Governador Mangabeira e com a proteção de sobreco de 69 kV do trafo 04T1 da SE Santo Antônio de Jesus, porém neste caso, por en foram utilizados os diagramas de tempo com o ajuste anterior, concluindo-se seletividade estava adequada, o que não ocorria para os ajustes implantados.

3.2. NORMATIVO

Nada a registrar.

4. ANÁLISE

4.1. ESTUDOS ELÉTRICOS

Nesta ocorrência, o defeito foi localizado na LT 02J4, Santo Antônio de Jesus/N entre o final do alcance da primeira zona e a SE Nazaré, ocorrendo portar descoordenação entre a segunda zona de proteção de distância da LT e a proteç sobrecorrente de fase do lado de 69 kV do transformador 04T1, pelas razões descri subitem 3.1.

4.2. CAPACITAÇÃO TÉCNICA

O técnico envolvido na graduação dessa proteção é experiente e estava habilitad realização dos estudos.
Os conhecimentos teóricos e práticos sobre essa proteção eram suficientes p execução da sua graduação.

5. DIAGRAMA DE CAUSA E EFEITO

Figura 1 (Última página)

6. CLASSIFICAÇÃO DA FALHA HUMANA

Referência: NM-TC-PA-GE-005, DPA, vigência 05/01/2004.

6.1. Quanto ao tipo:

6.1.1 Erro por lapso.

6.2. Quanto ao impacto ocasionado:

6.2.1 Desligamento por Falha Humana com corte de carga.

6.3. Quanto aos danos:

6.3.1 Nenhum.

7. PLANO DE AÇÃO

7.1. RECOMENDAÇÕES PRINCIPAIS

7.1.1. Divulgar ocorrência com equipe de estudos de proteção, destacando a impor
da confirmação dos ajustes efetivamente implantados.
Responsável: DOPR.
Prazo: Maio 2005.

7.1.2. Definir novos ajustes para a proteção de sobrecorrente de fase do lado de
do transformador 04T1 da SE Santo Antônio de Jesus, para atender os requ
de seletividade com a proteção da LT Santo Antônio de Jesus/Nazaré-02J4.
Responsável: DOPR.
Prazo: Fevereiro 2005 (Já concluído e implantado.)

8. CONCLUSÕES

O desligamento foi resultado de uma falha na verificação da seletividade entre as proteçõ
LT 02J4, Santo Antônio de Jesus/Nazaré-02J4 e do trafo 04T1 da SE Santo Antônio de
devido a utilização de diagrama de tempos de operação de proteções referentes ao a
anteriores da proteção do transformador, levando à conclusão errônea de existênc
seletividade.

ANNEX 7 – Human Error Report - RDFH –GRL 05/03

1.2. <u>Data e Hora</u> - 08/05/2003 – 08:22hs

1.3. <u>Descrição Sucinta da Ocorrência</u>

1.3.1. No dia 08 de maio de 2003, às 08:22 hs quando da realização de manobras para liberação do religador 21C1, foi aberta indevidamente em carga a fase vermelha da chave fusível 41C1-6, provocando o desarme automático dos disjuntores 11T1 e 12T1 com atuação das proteções 50A/C e 50A respectivamente, interrompendo o suprimento às cargas de 13.8 kV derivadas dos alimentadores 01C2, 01C3 e 01C4 (2,4 MW, durante 17 minutos) e do alimentador 01C1 (2,6 MW durante 28 minutos).

<u>HISTÓRICO DETALHADO</u>

2.1. CONFIGURAÇÃO DO SISTEMA ANTES DA PERTURBAÇÃO

Subestação de Currais Novos II, encontrava-se em sua configuração normal, conforme a guir:

- LT´s 03C1, 03M2, 02F1 e 02F2 energizadas e suprinda as cargas normalmente
- Trafos 03T1 e 03T2 energizados na sua configuração normal.
- Trafos 02T1-A, 02T1-B e 02T1-C energizados, suprindo as cargas de 13.8 kV da COSERN.

2.2. CRONOLOGIA DAS AÇÕES DA OPERAÇÃO

- 08:08Hs CROL/CRD desativaram religamento automático 21C2, 21C3 e 21C4 conforme PGM-CROL-0576/2003
- 08:09Hs CROL autorizou CRD liberar 21C1
- 08:10Hs CRD colocada chave 43-CLT do 21C1 na posição LOC.
- 08:15Hs CRD colocada chave normal/by-pass na posição by-pass
- 08:17Hs CRD fechada chave 41C1-6
- 08:20Hs CRD aberto religador 21C1
- 08:21Hs CRD aberta chave 31C1-4
- 08:22Hs CRD aberta fase vermelha da chave fusível 41C1-6, provocando o desarme automático dos disjuntores 11T1 e 12T1 com atuação das proteções 50A/C e 50A respectivamente.

2.3. SEQUENCIA DA RECOMPOSIÇÃO DAS CARGAS SE CRD

- 08:28Hs CRD colocada chaves CLT-21C2, 21C3 e 21C4 na posição LOC e abertos os citados religadores
- 08:33Hs CRD colocada chave CLT –12T1 na posição LOC e fechado 12T1
- 08:39Hs CRD fechado o disjuntor 11T1 e os religadores 21C2, 21C3 e 21C4
- 08:48Hs CRD fechadas chaves 31C1-4 e 31C1-5
- 08:50Hs CRD fechado o religador 21C1
- 08:52Hs CRD colocada chave normal/by-pass do 21C1 na posição normal
- 08:55Hs CRD ativado religamento automático dos religadores 21C2, 21C3 e 21C4

2.4. CARGAS INTERROMPIDAS

2.4.1. Houve interrupção do suprimento às cargas de 13.8 kv derivadas da SE CRD, associadas a:

- Alimentadores 01C2, 01C3 e 01C4 de 2,4 MW, durante 17 minutos;
- Alimentador 01C1 de 2,6 MW durante 28 minutos;

3. FATOS E DADOS RELEVANTES

3.1. OPERAÇÃO

- As manobras foram realizadas conforme programa, que constava de itens executados ora na sala de comando e ora no pátio da Subestação
- O operador conhece detalhadamente as manobras de liberação do religador 21C1 e estava com o programa de manobras em mãos, registrando cada passo da manobra
- O disjuntor 11T1 tem uma restrição pendente relativo ao circuito de fechamento, sendo necessário que antes de efetuar o comando do disjuntor, o operador dirija-se ao pátio e efetue o carregamento manual da mola de fechamento e retorne a sala de comando, para efetuar o comando de fechamento, o que implica em uma perda de tempo de aproximadamente cinco minutos

NORMATIVO

- Os procedimentos normatizados foram cumpridos normalmente.

3.2. CAPACITAÇÃO TÉCNICA

- O Operador envolvido na ocorrência é tecnicamente preparado para operar a SE CRD, não apresenta restrição de natureza técnica e passou pelo processo de Certificação Técnica com êxito

3.3. PROTEÇÃO

- Nada a comentar

4. ANÁLISE

4.1. OPERAÇÃO

4.1.1. Ao fazer a seleção da chave 31C1-5, o operador se confundiu e selecionou a chave 41C1-6, face ambas serem fixadas no mesmo chassi e terem um ponto comum (bloco do contato fixo da 31C1-5 e contato móvel da 41C1-6), embora ambas as chaves estivessem devidamente codificadas de forma clara e visível, além das canelas dos elos-fusíveis estivessem pintadas de amarelo.

4.2. PROTEÇÃO

- A proteção operou corretamente.

4.3. EQUIPAMENTOS

- Nada a registrar

4.4. PROJETO

- O arranjo das chaves 31C1-5 e 41C1-6 do alimentador 01C1 e dos demais alimentadores da SE CRD (foto 1 em anexo), utilizam o mesmo chassi e possuem um ponto elétrico comum (contato fixo da chave de dígito 5 e o contato móvel da chave de dígito 6), o que pode levar o Operador a confundir-se.

6. CLASSIFICAÇÃO DA FALHA

6.1. TAREFA

6.1.1. TIPO: (G) – Manobra programada, exercitada frequentemente e tendo-se conhecimento das implicações de falhas

6.1.2. RISCO NOMINAL: 0,0004

6.2. FATORES DETERMINANTES DO DESEMPENHO HUMANO

6.2.1. SITUACIONAIS : Ambientais – Projeto (Arranjo das chaves 31C1-5 e 41C1-6 Sobre o mesmo chassi, e com ponto comum entre ambas, confunde o operador)

6.2.2. INDIVIDUAIS : Homem - Auto-confiança (perda momentânea da concentração) Stressores – Regime de Trabalho (A equipe da SE CRD vem trabalhando com o quadro incompleto, ensejando trabalhos na folga)

6.3. DADOS COMPLEMENTARES:

6.3.1. INTERVALO DE DESCANSO ANTES DO TURNO: 101.389 (12:00)

6.4. QUANTIFICAÇÃO DO RISCO

6.4.1. RISCO NOMINAL DE FALHA OPERACIONAL (RN): 0,0004

6.4.2. RISCO ESTIMADO: (RE)= 0,0004

6.5. FALHA OPERACIONAL

6.5.1. GRAU DE SEVERIDADE: Falha afetando o consumidor

6.5.2. ERRO ESTIMADO: Erro de Comissão

8. CONCLUSÃO

- **Pelo exposto, concluimos que esta falha operacional foi motivada pela seleção errada do Operador da Instalação, ao confundir a chave 41C1-6 com a chave 31C1-5, por se encontrarem no mesmo chassi e terem um contato comum.**

9. ELABORAÇÃO

ANNEX 8 – HUMAN ERROR DATABASE: ERROR TABLE

ERRO	DATA	CARGA INTERROMPIDA (MW)	DURACAO INTERRUPCAO (MIN)	NIVEL ERRO RASMUSEN	TIPO ERRO REASON	MODO DE FALHA REASON	PROCESSO BERLINNER	COMPORTAMENTO ELEMENTAR BERLINNER
1	26/10/98	82,47	14,00	RULE	MISTAKE	ENCODING DEFICIENCES	COGNITIVE	COMPARE
2	18/10/98	66,23	3,00	RULE	MISTAKE	ENCODING DEFICIENCES	COGNITIVE	COMPARE
3	18/03/98	171,00	9,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	POSITION
4	08/09/98	70,00	56,00	SKILL	SLIP	OMISSIONS	PERCEPTIVE	MONITORED
5	02/10/98	126,20	15,00	SKILL	LAPSE	OMISSIONS	PERCEPTIVE	MONITORED
6	23/08/99	1,32	8,00	RULE	MISTAKE	COUNTERSIGNS AND NONSIGNS	PERCEPTIVE	LOCATED
7	26/05/99	9,54	13,00	RULE	MISTAKE	RULE STRENGHT	MOTOR	PUSH/PULL
8	29/09/99	40,00	18,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	PUSH/PULL
9	01/09/99	107,00	50,00	RULE	MISTAKE	COUNTERSIGNS AND NONSIGNS	MOTOR	MOVE
10	08/04/99	9,00	52,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	MOTOR	MOVE
11	30/03/99	36,00	19,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	REMOVE
12	06/03/99	11,00	8,00	RULE	MISTAKE	ENCODING DEFICIENCES	PERCEPTIVE	INSPECT
13	03/02/99	26,00	31,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	PUSH/PULL
14	25/11/99	4,00	2,00	RULE	MISTAKE	RIGIDITY	MOTOR	ADJUST
15	05/12/99	12,00	6,00	RULE	MISTAKE	COUNTERSIGNS AND NONSIGNS	COMMUNICATION	REGISTER
16	10/01/99	45,00	23,00	SKILL	LAPSE	PERCEPTUAL CONFUSIONS	MOTOR	ADJUST
17	11/07/99	400,00	1,00	KNOWLEDGE	MISTAKE	OVERCONFIDENCE	MOTOR	TYPING
18	20/09/99	38,80	5,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	REMOVE
19	16/08/99	0,60	73,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	DISCARD
20	21/09/00	12,00	36,00	KNOWLEDGE	MISTAKE	OVERCONFIDENCE	MOTOR	POSITION
21	17/09/00	75,00	12,00	RULE	MISTAKE	FIRST EXCEPTIONS	MOTOR	POSITION
22	26/06/00	1,50	41,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	COGNITIVE	DECIDE
23	30/04/00	221,00	27,00	RULE	MISTAKE	ENCODING DEFICIENCES	COGNITIVE	CHOOSE
24	15/03/00	16,00	3,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	COGNITIVE	DECIDE
25	11/11/00	10,00	2,00	RULE	MISTAKE	GENERAL RULE	COGNITIVE	COMPARE
26	11/10/00	60,00	11,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	REMOVE
27	04/09/00	28,00	10,00	RULE	MISTAKE	INFORMATION OVERLOAD	MOTOR	POSITION
28	23/03/00	99,40	150,00	RULE	MISTAKE	ACTION DEFICIENCES	PERCEPTIVE	INSPECT
29	10/08/00	110,00	11,00	SKILL	SLIP	OMISSION FOLLOWING INTERRUPTIONS	PERCEPTIVE	MONITORED
30	07/08/00	41,00	2,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	COGNITIVE	DECIDE
31	09/06/00	20,00	8,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	MOTOR	REMOVE
32	07/02/00	20,40	4,00	RULE	MISTAKE	INFORMATION OVERLOAD	COGNITIVE	DECIDE

ERRO	DATA	CARGA INTERROMPIDA (MW)	DURACAO INTERRUPCAO (MIN)	NIVEL ERRO RASMUSEN	TIPO ERRO REASON	MODO DE FALHA REASON	PROCESSO BERLINNER	COMPORTAMENTO ELEMENTAR BERLINNER
33	19/04/00	13,00	5,00	RULE	MISTAKE	INFORMATION OVERLOAD	COGNITIVE	DECIDE
34	25/05/00	6,60	1,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	PUSH/PULL
35	28/07/00	52,00	511,00	KNOWLEDGE	MISTAKE	CONFIRMATION BIAS	COGNITIVE	CHOOSE
36	22/01/00	15,00	16,00	SKILL	LAPSE	OMISSION	COGNITIVE	REMEMBER
37	17/12/00	18,00	1,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	COGNITIVE	HOLD
38	17/12/00	18,00	3,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	MOVE
39	18/12/01	60,52	130,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	REMOVE
40	07/06/01	90,30	9,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	REMOVE
41	03/04/01	64,40	23,00	SKILL	LAPSE	OMISSION	COGNITIVE	REMEMBER
42	07/09/01	34,00	14,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	COGNITIVE	COMPARE
43	09/10/01	13,20	13,00	RULE	MISTAKE	ENCODING DEFICIENCES	MOTOR	REMOVE
44	28/09/01	42,00	7,00	KNOWLEDGE	MISTAKE	OVERCONFIDENCE	PERCEPTIVE	IDENTIFY
45	22/09/01	144,00	13,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
46	20/04/01	8,00	6,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
47	01/05/01	4,80	6,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	COGNITIVE	REMEMBER
48	08/04/01	9,20	3,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
49	30/11/01	114,50	20,00	RULE	MISTAKE	RIGIDITY	COGNITIVE	DECIDE
50	18/12/02	1,00	10,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
51	23/11/02	6,00	5,00	RULE	MISTAKE	COUNTERSIGNS AND NONSIGNS	COGNITIVE	COMPARE
52	10/10/02	1314,60	64,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	MOVE
53	09/08/02	1,70	2,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
54	05/06/02	44,00	18,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
55	27/03/02	7,00	49,00	KNOWLEDGE	MISTAKE	CONFIRMATION BIAS	COGNITIVE	COMPARE
56	01/10/02	33,50	162,00	RULE	MISTAKE	ENCODING DEFICIENCES	COGNITIVE	COMPARE
57	19/03/02	84,00	2,00	SKILL	LAPSE	INVERSIONS	COGNITIVE	REMEMBER
58	22/10/02	55,50	211,00	SKILL	LAPSE	OMISSIONS	COGNITIVE	REMEMBER
59	12/04/02	24,90	4,00	RULE	MISTAKE	COUNTERSIGNS AND NONSIGNS	MOTOR	REMOVE
60	17/08/03	337,30	81,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	MOVE
61	26/05/03	5,00	23,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	COGNITIVE	COMPARE
62	17/10/03	3,10	3,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
63	08/05/03	5,00	28,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
64	06/05/03	1,00	1,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY

ERRO	DATA	CARGA INTERROMPIDA (MW)	DURACAO INTERRUPCAO (MIN)	NIVEL ERRO RASMUSEN	TIPO ERRO REASON	MODO DE FALHA REASON	PROCESSO BERLINNER	COMPORTAMENTO ELEMENTAR BERLINNER
65	08/08/03	8,30	5,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	MOVE
66	05/09/03	14,00	3,00	RULE	MISTAKE	RULE STRENGHT	PERCEPTIVE	IDENTIFY
67	29/04/03	14,62	19,00	SKILL	LAPSE	OMISSIONS	COGNITIVE	DECIDE
68	12/04/03	22,28	1,00	SKILL	LAPSE	OMISSIONS	COGNITIVE	REMEMBER
69	27/08/03	2,94	5,00	RULE	MISTAKE	ACTION DEFICIENCES	MOTOR	MOVE
70	25/05/03	31,00	6,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	COGNITIVE	COMPARE
71	29/03/03	152,00	21,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	COGNITIVE	COMPARE
72	13/11/04	241,50	30,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	PUSH/PULL
73	29/11/04	16,80	1,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	REMOVE
74	12/12/04	10,00	5,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
75	23/08/04	100,00	8,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	MOVE
76	29/07/04	10,00	72,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	COGNITIVE	REMEMBER
77	27/07/04	10,00	9,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
78	15/12/04	108,00	29,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	COGNITIVE	REMEMBER
79	21/09/04	58,00	23,00	SKILL	LAPSE	INVERSIONS	COGNITIVE	REMEMBER
80	17/05/04	3,50	6,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
81	23/03/04	11,70	3,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
82	29/11/04	55,78	9,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	MOVE
83	16/09/04	70,00	10,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	COGNITIVE	REMEMBER
84	04/03/04	220,00	74,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	REMOVE
85	21/03/04	31,80	46,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
86	19/02/05	87,00	85,00	SKILL	SLIP	ENCODING DEFICIENCES	COGNITIVE	DECIDE
87	10/06/05	15,00	81,00	RULE	MISTAKE	COUNTERSIGNS AND NONSIGNS	PERCEPTIVE	IDENTIFY
88	15/07/05	151,00	19,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
89	22/05/05	1,90	142,00	KNOWLEDGE	MISTAKE	COMFIRMATION BIAS	COGNITIVE	REMEMBER
90	16/10/05	15,00	5,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	MOVE
91	13/11/05	8,60	1,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
92	30/07/05	58,00	32,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
93	04/10/05	32,00	7,00	SKILL	LAPSE	INVERSIONS	COGNITIVE	REMEMBER
94	03/05/05	66,00	8,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
95	09/12/05	85,00	205,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	COGNITIVE	COMPARE
96	07/12/05	85,00	205,00	RULE	MISTAKE	ENCODING DEFICIENCES	COGNITIVE	DECIDE

ERRO	DATA	CARGA INTERROMPIDA (MW)	DURACAO INTERRUPCAO (MIN)	NIVEL ERRO RASMUSEN	TIPO ERRO REASON	MODO DE FALHA REASON	PROCESSO BERLINNER	COMPORTAMENTO ELEMENTAR BERLINNER
97	30/06/05	129,00	58,00	RULE	MISTAKE	ENCODING DEFICIENCES	COGNITIVE	COMPARE
98	10/01/05	66,13	21,00	RULE	MISTAKE	ENCODING DEFICIENCES	COGNITIVE	COMPARE
99	19/01/06	102,00	19,00	RULE	MISTAKE	RULE STRENGHT	COGNITIVE	DECIDE
100	06/11/06	269,90	21,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
101	08/06/06	1,40	1,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
102	08/08/06	6,00	2,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	COGNITIVE	REMEMBER
103	18/12/06	1,00	14,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
104	04/06/06	24,60	491,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	OBSERVE
105	22/03/06	20,00	13,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	REMOVE
106	05/02/06	5,00	45,00	RULE	MISTAKE	ACTION DEFICIENCES	COGNITIVE	DECIDE
107	16/09/06	126,57	36,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	COGNITIVE	COMPARE
108	26/07/06	68,00	363,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	COGNITIVE	COMPARE
109	23/03/06	32,00	13,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	MOVE
110	05/07/07	99,76	66,00	KNOWLEDGE	MISTAKE	OVERCONFIDENCE	COGNITIVE	DECIDE
111	23/03/07	98,41	29,00	RULE	MISTAKE	ENCODING DEFICIENCES	COMMUNICATION	REQUEST
112	13/07/07	3,20	7,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
113	29/04/07	45,91	76,00	RULE	MISTAKE	ENCODING DEFICIENCES	COGNITIVE	COMPARE
114	09/04/07	4,00	49,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	MOVE
115	27/03/07	53,00	25,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	MOVE
116	27/11/07	10,00	4,00	SKILL	LAPSE	INVERSIONS	MOTOR	MOVE
117	10/01/07	26,00	16,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	COGNITIVE	COMPARE
118	19/04/07	23,53	17,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	COGNITIVE	COMPARE
119	22/02/07	23,10	27,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	COGNITIVE	COMPARE
120	27/02/08	4,80	7,00	RULE	MISTAKE	ACTION DEFICIENCES	PERCEPTIVE	OBSERVE
121	11/11/08	14,00	6,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
122	18/08/08	1,16	1,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
123	28/05/08	37,63	7,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
124	14/08/08	38,00	62,00	KNOWLEDGE	MISTAKE	CONFIRMATION BIAS	COGNITIVE	COMPARE
125	25/01/08	3,67	18,00	RULE	MISTAKE	ENCODING DEFICIENCES	COGNITIVE	COMPARE
126	06/11/09	9,64	4,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	PERCEPTIVE	IDENTIFY
127	16/12/09	24,92	28,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	REMOVE
128	08/10/09	750,50	26,00	SKILL	SLIP	PERCEPTUAL CONFUSIONS	MOTOR	MOVE
129	01/03/09	199,00	17,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	COGNITIVE	COMPARE
130	25/08/09	15,10	16,00	KNOWLEDGE	MISTAKE	BIASED REVIEWING	COGNITIVE	COMPARE
131	02/08/09	9,96	8,00	SKILL	LAPSE	INVERSIONS	COGNITIVE	REMEMBER

ANNEX 9 – **SUMMARY OF OCCORENCE**

ERROR	YEAR	Load Interrupted	Summary of the concurrency	Classification
001	1988	82,47MW	- Para atender a uma solicitação de programação da GRO, no 500KV, o CROO elaborou / enviou o roteiro de manobras para o CRON, o qual constava da abertura do 14L1/SE SBD e em seguida a abertura do disjuntor 14L1/SE PRI. - Quando da execução da manobra de abertura do 14L1 em PRI, e estando as chaves 85CO na posição "ON" e a 43PPS na posição L1, ocorreu o desligamento automático da LT04S1 SBD/FTZ, ficando a barra de 69KV da SE/SBD desenergizada. - A equipe do SNCP foi deslocada para SE/SBD, em função da ocorrência do dia 18/10/98, e após intervenção foi detectado o problema, ou seja, a programação dos contatos da chave 43PPS instalada, divergindo do projeto.	**RASMUSSEN** Rule; mistake; **REASON** Encoding deficiencies **BERLINNER** Cognitive - Compare One wrong rule was applied correctly plan; plan incorrect
002		66,23MW	- Após a ocorrência (desligamento) do dia 26/10/98, que será explanado em um relatório específico, é que foi verificado ser a programação inadequada da chave, a causa do desligamento, pois isto levou o potencial de trip que surgiu em função da abertura do 14L1 em PRI, lógica de subtensão, associado ao fato de que a chave 85CO estava na posição "ON", a desligar também a LT04S1.	Rule; mistake; Encoding deficiencies Cognitive - Compare One wrong rule was applied correctly plan; plan incorrect
003		171,00MW	Por ocasião da realização das manobras de liberação do 12J2 para o SLMG efetuar a instalação da chave seletora de comando (L R M), conforme programado, houve a abertura indevida da chave 32J1-4 ao invés da 32J2-4, ocasionando o desligamento de todas as cargas da S/E NTD, a partir dos disjuntores 14V1 da S/E NTD e 14V2 da S/E CGD, com perda de 171 MW a exceção das cargas de MCB (4,0 MW) que permaneceram supridas através da LT 02M1(SE STD). O retorno das cargas iniciaram a partir das 08:02 horas.	Skill; slip; Perceptual confusions Motor - Position Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
004		70,00MW	Ocorreu desarme geral da SE devido a explosão do disjuntor 11E2. Na re-energização o operador errou a seqüência de manobras.	Skill; slip; Omissions Perceptive - Monitored

				Step execution is out of order planned inversion sequence
005		126.20MW	O gerador 01G5 foi desenergizado parado e liberado para que a DRUB instalasse um sistema de monitorização no mesmo. Aproveitando a parada da máquina, foram solicitadas outras intervenções, entre as quais a substituição do casco do trocador de calor do sistema de refrigeração dos tiristores. Quando do retorno da unidade geradora, não foi energizada a moto bomba do referido sistema de refrigeração, o que provocou o desligamento da máquina.	Skill; lapse; Omissions Perceptive - Monitored Failure to memorize the actions and/or objects. memory; plan correct, action incorrect
006	1 9 9 9	1,32MW	Após os trabalhos de aferição/calibração, concluído às 15h30min, o técnico responsável pela intervenção entra em contato com o eng. º do SNCP informando do problema verificado e o mesmo avisou ao operador encarregado do turno, do atraso na reposição do referido relé, visto os danos observados, mas que entraria no horário de ponta com a cadeia de proteção recomposta. Quando da colocação do relé, às 17h29min, houve o desarme do disjuntor 11W1. Após uma tentativa de fechamento do disjuntor 11W1, houve novamente o desarme, onde detectou-se que a fiação da bobina de selo do relé estava partida e encostando no contato de saída do trip.	Rule; mistake; Countersigns and nonsigns Perceptive - Located One correct rule was applied incorrectly. plan; plan incorrect
007		9,54MW	Durante a execução das atividades, o responsável da intervenção detectou falha no circuito de supervisão de “anormalidade de disjuntor e seccionadora”, e, no intuito de corrigir o problema, pressionou o relé 62X da cadeia de proteção da LT 04L1, causando toda a ocorrência em pauta ao sistema.	Rule; mistake; Rule strength Motor – Push/Pull One correct rule was applied incorrectly. plan; plan incorrect
008		40,00MW	Desligamento acidental da unidade 01G2 com perda de 40 MW durante 18 minutos, provocado pelo acionamento indevido de desligamento do quick-lag 19 que alimenta o conversor do seqüenciador e instrumentação da máquina, acarretando trip e bloqueio da mesma.	Skill; slip; Perceptual confusions Motor – Push/Pull Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
009		107,00MW	Às 11h54min do dia 01/09/1999, houve o desligamento automático da barra de 230kV/04B1 da Subestação do FUNIL (SE FNL), provocado por curto-circuito decorrente de manobra em carga da chave de by pass 34E2-6.	Rule; mistake; Countersigns and nonsigns Motor - Move One correct rule was applied incorrectly. plan; plan incorrect
010		9,00MW	Desligamento automático do disjuntor 12C1 por atuação da proteção de sobre corrente de fase em decorrência da abertura da chave 31C1-6 em carga durante processo de manutenção.	Knowledge; Mistake; Biased reviewing Motor - Move

				One correct rule was applied incorrectly. plan; plan incorrect
011		36,00MW	Ao ser retirada a fiação do ponto 1 (desenergizado) da chave de tensão PKB, a fiação do ponto 2 (energizado) soltou-se também do terminal, provocando curto-circuito para a terra e conseqüente queima do fusível de proteção do circuito localizado na caixa de ligação dos TP´s da barra de 69 kV, no pátio. Os dois fios faziam parte de um mesmo “chicote”, com amarração comum.	Skill; slip; Perceptual confusions Motor - Remove One correct rule was applied incorrectly. plan; plan incorrect
012		11,00MW	o SSCP programou inspeção/ensaios no esquema, constatando que a temporização (62-1) do relé 81 estava incorreta, sendo encontrado um valor ajustado de 5,0s, quando o valor definido pela Ordem de Ajuste é de 11,0s.	Rule; mistake; Encoding deficiencies Perceptive - Inspect One wrong rule was applied correctly plan; plan incorrect
013		26,00MW	Colocada a chave 43T5 na posição “ET”, confirmada “CLT” na posição local e fechado o disjuntor 14T5 , neste mesmo instante o operador ao se deslocar para efetuar abertura do 14D1, posicionou-se defronte ao 14T4 (que fica localizado ao lado do 14D1), abrindo-o indevidamente, com perda de 26MW,	Skill; slip Perceptual confusions Motor – Push/Pull Wrong object selected due similarity with desirable object. ; action; plan correct, action incorrect; wrong selection
014		4,00MW	O Operador envolvido na ocorrência, não utilizou a Instrução Interna existente na Instalação que discrimina todos os passos a serem seguidos no processo de mudança de ajuste de relés.	Rule; mistake; Rigidity Motor - Adjust The operator doesn’t have ready rules, than He improvises new rules. plan; plan incorrect.
015		12,00MW	não foi observado pela equipe de proteção, apesar de ser questionada quanto a existência de relés de distância, que essa LT possuía proteção de sobre corrente com restrição de tensão, de forma que, quando da desenergização do 02BP, tivemos a atuação da proteção 51VA/B/C, provocando por conseguinte a abertura do 14M1, com perda de 12MW, associada às cargas da LT 02L4.	Rule; mistake; Countersigns and nonsigns Communication - Register Failure to memorize the actions and/or objects. Memory; plan correct action incorrect.
016		45,00MW	O motivo identificado como causador da ocorrência, foi a colocação do TAP de seleção de freqüência em 50Hz, quando da aferição do relé 67N de fabricação SIEMENS tipo 7SK88 no comissionamento.	Skill; lapse; Perceptual confusions Motor - Adjust

				One correct rule was applied incorrectly. plan; plan incorrect
017		400,00MW	O Operador envolvido apresenta um ótimo nível de capacitação, tendo inclusive exercido a função de Encarregado da Instalação, porém, mesmo considerando que houve uma grave falha do equipamento durante a manobra, admite-se que o excesso de autoconfiança levou a tomar uma atitude precipitada.	Knowledge; mistake; Overconfidence Motor - Typing The operator doesn't have ready rules, than He improvises new rules. plan; plan incorrect.
018		38,80MW	Quando da sua desconexão na régua C13-9, o terminal C13-9-1 tocou na parte metálica do painel (terra) provocando trip direto no disjuntor 14L1 através do primeiro circuito de abertura. Em conseqüência disso, o relé 94L foi energizado enviando transfer-trip para o terminal remoto (SE BRA). Esta desconexão de ponto energizado não estava prevista no programa executivo da intervenção.	Skill; Slip; Perceptual confusions Motor - Remove One correct rule was applied incorrectly. plan; plan incorrect
019		0,60MW	No dia 16.08.99, as 13:47 h, uma equipe terceirizada, contratada pela SPMA, executava roço na faixa de alimentador 01C4 ZBU/ BARRAGEM MÓVEL quando um galho de árvore foi jogado pelo vento sobre os seus condutores no instante que ele foi cortado, provocando um curto-circuito que ocasionou a abertura automática do religador 21C4 e dos disjuntores 12T2 e 12T3, o desligamento da barra 01B1 ZBU alem do alimentador 01C4, a avaria de dois isoladores da chave 31C4-4, o rompimento de três pulos (fases a, b, c) dessa chave e dois outros pulos na primeira estrutura do alimentador 01C4. A equipe de roço subestimou o risco de acidente e infringiu uma recomendação básica de segurança, a saber, prender os galhos com corda antes de cortá-lo.	Skill; Slip; Perceptual confusions Motor - Discard One correct rule was applied incorrectly. plan; plan incorrect
020	2000	12,00MW	Excesso de confiança do operador supervisor de turno da SE MLG e descumprimento do normativo pelo mesmo, pelo encarregado da SE MLG e pelo operador de sistema auxiliar.	Knowledge; mistake; Overconfidence Motor - Position The operator don't have ready rules, than He improvises new rules. Plan; plan incorrect.
021		75,00MW	Como causa fundamental conclui-se que o circuito de controle do trafo de terra que corta o Trip das proteções intrínsecas, ao se abrir a chave 32ª1-8 é inadequado por manter o selo do rele 94TT sobre a chave 86TT, bem como a não existência de supervisão de atuação da bobina do rele 94TT, constituindo assim, uma armadilha para a operação e manutenção.	Rule; mistake; First exceptions Motor - Position One wrong rule was applied correctly plan; plan incorrect
022		1,50MW	O desempenho da operação não foi satisfatório, tendo em vista, o não cumprimento do novo procedimento pelo operador executante das manobras (informando desconhecer)	Knowledge; mistake; Biased reviewing Cognitive - Decide The operator doesn't have ready rules, than

				He improvises new rules. Plan; plan incorrect.
023		221,00MW	A causa da atuação das chaves de bloqueio foi a troca de programação do contato 9/10 do relé 94TT, que deveria ser um contato normal aberto, sendo colocado um contato normal fechado.	Rule; mistake; Encoding deficiencies Cognitive - Choose One wrong rule was applied correctly plan; plan incorrect
024		16,00MW	Faltou à equipe de manutenção do SNMM, responsável pela execução das tarefas, uma melhor análise (programação executiva das atividades a serem desenvolvidas), portanto o seu desempenho não foi satisfatório nessa intervenção.	Knowledge; mistake; Biased reviewing Cognitive - Decide The operator doesn't have ready rules, than He improvises new rules. Plan; plan incorrect.
025		10,00MW	No entendimento do OPS, a manobra de normalização da SE ITH deveria ser idêntica à manobra realizada para transferência da carga para a SE Estância, no início da ocorrência. Não observou, contudo que a situação do restabelecimento era diferente da inicial, quando a SE ITH foi desligada intempestivamente devido ao defeito na LT 04L1.	Rule; mistake; General Rule Cognitive - Compare Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
026		60,00MW	Ás 11h: 32min do dia 11/10/2000, ocorreu o desligamento da LT 04L2 CTG/SIBRA causado pelo contato acidental da mão do mantenedor nas navalhas associadas ao contato 12/13 do relé auxiliar de trip ZNA, tipo AR-8, da cadeia de proteção de distância WENCO da referida LT. Esta condição ocorre quando o relé de religamento encontra-se desativado. O SSCP executava os procedimentos de limpeza (MP Programada) dos relés extraíveis.	Skill; Slip; Perceptual confusions Motor - Remove One correct rule was applied incorrectly. plan; plan incorrect
027		28,00MW	No dia 04/09/2000 às 22h43min h, houve o desarme da barra de 69KV da SE GVM, após tentativa sem sucesso de energização da LT 02V2 que estava entregue à concessionária. A tentativa foi feita pelo disjuntor de transferência 12D1 sem que a proteção do terminal 02V2 houvesse sido transferida, fazendo com que a proteção de retaguarda 51N-T do transformador de aterramento 02ª1 atuasse, abrindo automaticamente os disjuntores associados à barra 02BP.	Skill; slip; Informational overload Motor - Position Step execution is out of order planned. inversion sequence
028		99,40MW	A empresa contratada falhou na execução dos serviços, uma vez que não estava realizando a verificação do "munhão" utilizando o parafuso gabarito, antes de cada intervenção. Também estava erradamente posicionada a porca de segurança (porca de espera), afastada ± 20 cm do "munhão" principal, em vez de justaposta.	Rule; mistake; Action deficiencies Perceptive - inspect

				One step is not realized. action; plan correct action incorrect; omission
029		110,00MW	Efetuou os testes de atuação do esquema de falha, quando houve o desligamento dos disjuntores 14T3 e 14T4 pela operação do relé KK. Tal relé é auxiliar do esquema de falha 3 (62BF), provocando a perda da barra de 69 e 13.8 kV da SE CGD com as respectivas cargas derivadas;	Rule; mistake; Omission following interruption Perceptive - Monitored One step is not realized. action; plan correct action incorrect; omission
030		41,00MW	Durante processo de liberação do disjuntor 12J8 da SE MRD, para SLMG efetuar Manutenção Preventiva Programada, foi executada a abertura do disjuntor 12J8, sem o devido fechamento da chave 32J8-6.	Knowledge; mistake; Biased reviewing Cognitive - decide One step is not realized. action; plan correct action incorrect; omission
031		20,00MW	Quando terminou de tirar o pino da haste, o eletricista do pólo 1 deu um leve torque na coluna giratória da chave afim de soltar por completo o seu lado da haste, pensando que o outro eletricista ainda não tinha retirado o pino do outro lado. Porém nesse momento o eletricista do pólo 2 já havia retirado o pino e aguardava a corda para amarrar a haste. Foi quando ficando livre a haste caiu em direção ao solo colidindo com os cabos condutores.	Knowledge; mistake Biased reviewing Motor - Remove Step execution is out of order planned. inversion sequence
032		20,40MW	Abertura automática dos disjuntores 12T1, 12F1 e 12F2, da S/E CRD no dia 07 de fevereiro de 2000, às 12h20min, por atuação do relé 27 do esquema de alívio de carga provocando corte de 20,4 MW da COSERN durante 4 minutos, face não desativação do relé 27 durante manobras de abertura do Anel Norte/Leste.	Rule; mistake; Informational overloaded Cognitive - Decide One step is not realized. action; plan correct action incorrect; omission
033		13,00MW	Durante os trabalhos de isolamento do 12T1/PIC para manutenção preventiva, o operador de instalação após abrir através do comando manual a chave 32T1-5, fechou mesmo não constando no programa de manobras a chave 32T1-7, aterrando o trecho energizado entre a chave 32T1-6 e o trafo 04T1.	Rule; mistake; Informational overloaded Cognitive - Decide Failure to memorize the actions and/or objects. memory; plan correct action incorrect
034		6,60MW	Durante os trabalhos de manutenção preventiva nível “0” no religador 01Y6/TSA, o mantenedor abriu e fechou indevidamente o religador 01Y3/TSA.	Skill; slip;. Perceptual confusions Motor – Push/Pull

				The operator doesn't have ready rules, than He improvises new rules. plan; plan incorrect
035		52,00MW	A inexistência de procedimento da manutenção mecânica e a identificação deficiente nos terminais, levaram o mecânico de manutenção a conectar erradamente as mangueiras de interligação entre a unidade de bombeamento e as tubulações fixas, gerando uma não-conformidade que não foi detectada pela inspeção posterior da Operação, permanecendo a anormalidade que gerou o desligamento da unidade geradora.	Knowledge; mistake; Confirmation bias Cognitive - Choose The operator doesn't have ready rules, than He improvises new rules. plan; plan incorrect.
036		15,00MW	A desativação do relé 94L do disjuntor 14L1 da SE BJS, responsável pelo envio de transfer-trip ao disjuntor 14T1 da SE BRA, estava prevista no Programa executivo da equipe de Proteção. Este passo não foi cumprido, tendo sido a causa fundamental do desligamento do trafo 04T1 da SE BRA.	Skill; lapse; Omissions Cognitve - Remember One step is not realized. action; plan correct action incorrect; omission
037		18,00MW	Na descida do segundo ormezo o montador acidentalmente soltou o "came along" da alça do cabo sem alertar adequadamente o auxiliar da linha de mão, resultando que o cabo de aço de meia polegada, com o peso equivalente aos cinqüenta metros de extensão, imediatamente desceu com velocidade excessiva. Ato contínuo, assustado com os gritos de alerta da supervisão, o auxiliar, em vez de reter soltou de vez a linha de mão e o cabo precipitou-se por inteiro sobre o cavalete, tendo sua extremidade livre, a ré, penetrado por entre o X de cordas da proteção lateral e tocado simultaneamente nas fases B e C causando um curto circuito bifásico que provocou o desligamento da LT.	Skill; slip; Perceptual confusions Motor - Hold One correct rule was applied incorrectly. plan; plan incorrect
038		18,00MW	Saída permanente da LT 02J2 devido a curto circuito, ocasionado por contato acidental com corda-linha de mão umedecida, devido ao contato com terreno molhado, durante trabalhos de encabeçamento de cadeias de amarração na estrutura 29/4 da LT CMD-PTU-U2-230kV em construção,	Skill; slip; Perceptual confusions Motor - Move One correct rule was applied incorrectly. plan; plan incorrect
039	2001	60,52MW	A causa principal dessa ocorrência deveu-se à desatenção do eletricista quando da retirada do cabo de alimentação auxiliar da furadeira que fora utilizada para execução do reforço estrutural da chave seccionadora 34T1-2.	Skill; slip; **Perceptual confusions** Motor - Remove Failure to memorize the actions and/or objects. memory; plan correct action incorrect
040		90,30MW	Durante a retirada do jumper do relé 68X-2 com o 68X-4, localizado na parte superior direita da tampa do painel 5R (painel tipo Westinghouse), o mesmo tocou na ferragem do painel, ocasionando saída trip através do Relé 21.1 instantâneo. Após a saída da LT 04C1 BNB/RSD, a equipe analisou a ocorrência,	Skill; slip; **Perceptual confusions** Motor - Remove

				action; plan correct action incorrect
041		64,40MW	Conclui-se que a causa da ocorrência foi a não colocação da chave 43-14L1 na posição “T”, após o fechamento da 34L1-6, durante a liberação do 14L1, o que causou a atuação da proteção falha do disjuntor, com conseqüente envio de transfer-trip para a S/E-BNB, e desarme da LT 04C1 Banabuiu / Russas.	Skill; slip; **Omissions** Cognitive - Remember One step is not realized. action; plan correct action incorrect; omission
042		34,00MW	O desligamento tratado neste relatório foi provocado por erro de execução introduzido durante o comissionamento do equipamento, em 1990. Apesar de várias MP terem sido realizadas desde então, os procedimentos de medição de grandezas adotados durante os ensaios não foram suficientes para identificar a anormalidade na RTC do circuito de corrente de neutro.	Knowledge; mistake; **Biased reviewing** Cognitive - Compare One wrong rule was applied correctly plan; plan incorrect
043		13,20MW	Para esta falha, a causa fundamental foi a desconexão incorreta dos pontos de trip do relé de gás, agravada pela costura da proteção existente na parte interna da fiação da régua X1, confundindo-se com a fiação original do equipamento.	Rule; mistake; **Encoding deficiencies** Motor - Remove Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
044		42,00MW	O operador não confirmou a posição da chave 32T1-5 após a ordem de comando de fechamento. Houve excesso de confiança do operador nos mecanismos de comando remoto da chave, tanto que passou para o item seguinte do RTM sem a confirmação visual , através da lâmpada de supervisão, do fechamento da 32T1-5;	Knowledge; mistake **Overconfidence** Perceptive - Identify One step is not realized. action; plan correct action incorrect; omission
045		144,00MW	Na volta ao painel CP6 para tentativa de novo reset, houve acionamento indevido do rele auxiliar que proporciona a transferência das proteções do 14T1 para o 14D1, que é similar a chave 86-04T1 e fica próxima a esta. Com isso, o trip do relé 87 foi transferido para o disjuntor 14D1 (que por sua vez encontrava-se transferindo o 14T3) desligando o transformador 04T3. Em seguida o trafo 04T2 saiu por sobrecarga, com atuação das proteções 50/51A e 86-04T2, desligando a barra de 69 KV da SE RLD.	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
046		8,00MW	Em seguida o operador dirigiu-se ao painel do 12J1, (vizinho e idêntico ao do 12J2), efetuou a abertura do 12J1 (pensando estar procedendo a abertura do 12J2),	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
047		4,80MW	o Operador manobrou indevidamente para fechamento a chave 32J2-6 com a chave terra 32J2-7 fechada, atuando o relé 51-N (I), desarmando o disjuntor 12D1, desenergizando o trafo 02T3 e a barra 01B2.	Knowledge; mistake; **Biased reviewing** Cognitive - Remember

				Failure to memorize the actions and/or objects. memory; plan correct action incorrect
048		9,20MW	o Operador de Instalação ao realizar o item 2.5 do Programa de Manobras, em vez de dar o comando de abertura para o disjuntor 12T3/SJI, inadvertidamente deu o comando de abertura para o disjuntor 12J2/SJI, desenergizando a LT 02J2/SJI/EMT.	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
049		114,50MW	Provocado por um aterramento temporário indevido e não autorizado durante as manobras de liberação do disjuntor,	Rule; mistake; **Rigidity** Cognitive - Decide Step execution is out of order planned. inversion sequence
050	2 0 0 2	1,00MW	Na execução da manobra de normalização do disjuntor 21Y5, que se encontrava transferido pelo 11D1, após fechamento das chaves seccionadoras 31Y5-4 e 31Y5-5, com vara de manobra, o Operador da Instalação (OPI) verificou que a fase A da chave 31Y5-5 não havia fechado corretamente. Na tentativa de refazer esta manobra, o OPI manobrou, por engano, a chave vizinha 31Y5-6 fase A, em carga, causando o desligamento automático do disjuntor 21D1 e a conseqüente desenergização do alimentador 01Y5.	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
051		6,00MW	o operador de Instalação da SE SMD, interpretou como falta de tensão geral da SE SMD e comandou a abertura dos disjuntores 13T1, 12M1 e 51H2, interrompendo o suprimento às cargas de 69 e 13.8 kV derivadas da SE SMD	Rule; mistake; **Countersigns and nonsigns** Cognitive - Compare Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
052		1.314,60MW	A equipe de TLE do START encontrava-se executando manutenção preventiva de substituição de isoladores e ferragens oxidadas na LT, conforme SI SLML 670/2002,quando ao substituir um dos cordões de isoladores da cadeia "V",na estrutura 77/1, seus eletricistas não atrelaram adequadamente um dos isoladores na ferragem de sustentação, vindo este cordão formado pelos isoladores a se desconectar quando do tensionamento da cadeia, o que, num movimento pendular após o desprendimento, aproximou os condutores desta fase à estrutura metálica, provocando o curto-circuito fase terra com o Conseqüente desligamento da LT.	Skill; slip; **Perceptual confusions** Motor - Move action; plan correct action incorrect
053		1,70MW	O operador (do pátio) recém chegado a sala de comando dirigiu-se para o painel de comando dos religadores e indevidamente acionou o punho da chave 101 do 21Y4 abrindo-o, notando a falha fechou-o em seguida. Logo depois acionou a chave 101 do 21Y3 abrindo-o, interrompendo a carga de 1,7 MW, observando a segunda falha solicitou ao colega (operador da sala de comando) para informar o CROL e solicitar autorização para normalizá-lo.	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action

				incorrect; wrong selection
054		44,00MW	Os pontos de alarme (C6-2-3) e trip (C6-2-2) do esquema de falha, localizados no chassi CP6, estão dispostos em pontos adjacentes na mesma régua. Na tentativa de acionar o circuito de alarme de falha do disjuntor 14T1, concluiu-se, após análise, que tenha havido acionamento indevido no ponto de trip.	Skill; slip; **Perceptual confusions** Perceptive - Identify One wrong rule was applied correctly plan; plan incorrect
055		7,00MW	O desligamento do disjuntor 12J1 durante as manobras de normalização previstas no PGM-CROL-377/02, elaborado de acordo com o conteúdo do RTM-STD-P-2004 teve como causa primária erro na análise pré-operacional e na seqüência de manobras do RTM que não considerou a transição de alimentação da cadeia de proteção do 12J1 entre os TC's do 12J1 (RTC 150/5 A) e os TC's do 12D1 (400/5 A),	Knowledge; mistake; **Confirmation Bias** Cognitive - Compare One wrong rule was applied correctly plan; plan incorrect
056		33,50MW	O desligamento acidental das barras de 13.8 kV da subestação de Teresina ocorreu por falta de implantação de ajustes nos transformadores de corrente-TC's que alimentam as proteções de sobrecorrentes lado 230 kV associadas aos trafos 04T1 e 04T2/TSA, quando da entrada em operação das linhas de transmissão-LTs 04L3 e 04L4 Teresina II/Teresina e do segundo trafo de aterramento 02ª2/TSA, o que provocou um considerável aumento do nível de curto-circuito nessa subestação.	Rule; mistake; **Encoding deficiencies** Cognitive - Compare One wrong rule was applied correctly plan; plan incorrect
057		84,00MW	Durante a execução das manobras de transferência para liberação do disjuntor 14L3, visando intervenção de urgência para substituir o conector trincado da chave 34L3-5, fase C, o operador executou o item 1.7 (Abrir o disjuntor 14L3) da Ordem de Manobras ao invés do item 1.4 (Fechar o disjuntor 14D1).	Skill; slip; **Reversals** Cognitive - Remember Step execution is out of order planned. inversion sequence
058		55,50MW	Na execução da intervenção para incorporação do disjuntor 12T1 na SE BRA, o passo a passo do planejamento executivo foi descumprido no item que seria passar a chave 43T para a posição **T** antes de manobrar o disjuntor, sendo manobrado na posição **N,** causando o desarme das LT's 02V3, 02V4**,** 02V5 e 02V6 e, estando o disjuntor 14T1 by-passado para manutenção, enviando Transfer Trip para a SE BJS, com conseqüente desarme da LT 04L1-BJS-BRA.	Skill; slip; **Omissions** Cognitive - Remember Step execution is out of order planned. inversion sequence
059		24,90MW	No momento da desconexão da fonte OS-10 do relé THR, ponto OS-10-83, localizado nos bornes de régua 79-50 do religador da cadeia, percebeu-se um pequeno centelhamento e tornou-se a conectá-lo novamente, gerando um surto através da fonte do relé THR, liberando um TRIP pelo cabo acima citado, através do 2º circuito do disjuntor 14L1, provocando o desarme da LT 04L1.	Rule; mistake; **Countersigns and nonsigns** Motor - Remove Repetition of one step already done action; plan correct action incorrect; repetition

060	2 0 0 3	337,30MW	Às 09h03minh, quando um eletricista já na posição de trabalho seguro por cinto de segurança abaixou-se, a sacola apoiou-se em seu joelho provocando a queda de uma ferramenta exatamente em cima do isolador (isolador de vidro) da chave 32L4-4 partindo-o e rompendo o isolamento da chave, provocando um curto-circuito neste polo.	Skill; slip; **Perceptual confusions** Motor - Move action; plan correct action incorrect
061		5,00MW	Desligamento automático do trafo 03T9, 138/13,8kV, por atuação da proteção diferencial (87) durante curto-circuito externo, provocado por erro de implantação de ajuste, ocasionando a desenergização das barras 01B4/01BP de 13,8kV.	Knowledge; Mistake; **Biased reviewing** Cognitive - Compare One correct rule was applied incorrectly. plan; plan incorrect
062		3,10MW	A equipe do SLCP solicitou então que a operação acompanhasse os novos ensaios, e deslocou-se para o painel de proteção da LT 02J2 onde atuou o relé 51_ A . Após ouvir o alarme do anunciador, a equipe dirigiu se para verificar e resetar o alarme, notando então que o 12J2 ainda estava fechado e 12D1 era que havia aberto, percebendo aí que tratava se de um desligamento acidental,	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
063		5,00MW	Ao fazer a seleção da chave 31C1-5, o operador se confundiu e selecionou a chave 41C1-6, faces ambas serem fixadas no mesmo chassi e terem um ponto comum (bloco do contato fixo da 31C1-5 e contato móvel da 41C1-6), embora ambas as chaves estivessem devidamente codificadas de forma clara e visível, além das canelas dos elos-fusíveis estivessem pintadas de amarelo.	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
064		1,00MW	Logo após a ocorrência da abertura indevida do 11L1 o operador de sistema envolvido percebeu a ação equivocada, através do display do SAGE, e executou de imediato a sua recomposição, após 7(sete) segundos.	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
065		8,30MW	Após haver conectado os pulos nas fases "A" e "B" durante a execução da etapa para conexão do pulo na fase "C", o eletricista de TLE trabalhando ao potencial aproximou o pulo da fase "B" rompendo a distância de isolamento elétrico.	Skill; slip; **Perceptual confusions** Motor - Move action; plan correct action incorrect
066		14,00MW	O desligamento indevido do religador se deu em virtude da **desatenção do operador provocado pelo estresse e cansaço,** à falta de sinalização na chave de comando no painel do religador que estava sendo liberado, e pela **falta de planejamento para execução da manobra não programada.**	Rule; mistake;. **Rule Strength** Perceptive - Identify

				The operator doesn't have ready rules, than He improvises new rules. plan; plan incorrect
067		14,62MW	Por uma decisão precipitada da coordenação das equipes de manutenção em avançar uma etapa do PGM(anexo I), referente a conexão dos pulos energizados da primeira estrutura da LT 04F1-TSA/PR ao terminal sob intervenção, sem o conhecimento da equipe de operação de instalação/sistema: os trabalhos não foram devolvidos a operação;	Skill; slip; **Omissions** Cognitive - Decide Step execution is out of order planned. inversion sequence
068		22,28MW	Às 12:24h do dia 12/04/2003 houve abertura acidental do disjuntor 12W1 da SE Picos sem sinalização de proteção, quando da simulação de abertura/fechamento do referido disjuntor para manutenção corretiva, devido o operador de instalação não ter colocado todas as chaves CLTs na posição local, conforme a solicitação de intervenção.	Skill; slip; **Omissions** Cognitive - Remember One step is not realized. action; plan correct action incorrect; omission
069		2,94MW	A causa do desarme foi curto-circuito fase-terra, fase "A", através do centelhador, durante montagem do andaime isolante, por diminuição do dielétrico. A peça metálica do andaime se aproximou das duas partes do centelhador diminuindo assim este isolamento.	Rule; mistake; **Action deficiencies** Motor - Move action; plan correct action incorrect
070		31,00MW	O desligamento foi resultado de uma falha na definição dos ajustes do sensor de direcionalidade da proteção de sobre corrente direcional de neutro dos terminais de Sapeaçu e Funil da LT 04F3 SPU/FNL durante os estudos realizados pela FLUXO para adequação da graduação para a entrada em operação do sistema da TSN, não detectado na fase de homologação dos mesmos pela DOPR.	Knowledge; mistake; **Biased reviewing** Cognitive - Compare The operator doesn't have ready rules, than He improvises new rules. Plan; plan incorrect.
071		152,00MW	O relé 67 operou indevidamente com a corrente de carga no sentido inverso da direcionalidade devido a falha na graduação do relé.	Knowledge; mistake; **Biased reviewing** Cognitive - Compare One wrong rule was applied correctly plan; plan incorrect

072	2004	241,50MW	Deficiência no processo de execução da lavagem de isoladores, pelo operador da pistola.	Skill; slip; **Perceptual confusions** Motor – Push/Pull action; plan correct action incorrect
073		16,80MW	Reiniciado o processo de implantação do relé curinga, e no momento de retirada de operação do relé titular, foi aberta a chave de teste de tensão, ao invés da chave de teste de corrente, ocasionado, desta forma, a operação da cadeia de proteção e conseqüente desarme do disjuntor 12J1.	Skill; slip; **Perceptual confusions** Motor - Remove

				Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
074		10,00MW	No dia 13/12 / 2004, às 19:55h, horário operacional, foi dado comando de parada indevida do 06G2, na UFL. No momento da ocorrência, o operador tentava dar um comando de parada em vazio no 06G3 para atender um teste de partida e parada em vazio solicitado pela manutenção. Indevidamente, comandou a parada do 06G2 ocasionando o desligamento da máquina com perda de geração de 10 MW durante 05 minutos.	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
075		100,00MW	O mantenedor encontrava-se sentado no interior do painel duplex 1R da LT 04L2 fazendo adequações/conexões de pontos do SOE. Após uns quinze minutos nessa posição, levantou se para retirar a cadeira a fim de acessar a parte inferior do painel, tocando nesse instante com a cabeça no conjunto de relés auxiliares (AR-1, LPX, ZX3B, ZX3A e 67NX) instalados na parte inferior da portinhola interna alta existente no painel, provocando a atuação do relé auxiliar instantâneo de trip ZX3-B, tipo AR-4 da Wenco, que ocasionou a abertura automática do disjuntor 14L2.	Skill; slip; **Perceptual confusions** Motor - Move action; plan correct action incorrect
076		10,00MW	Diante da configuração encontrada pelo SSMF após a ocorrência e consulta ao executante da intervenção de limpeza, pôde-se concluir que houve um descuido do mantenedor que, na intenção de liberar a passagem de água pelo "by-pass", ao invés de abrir as duas válvulas (anterior e posterior ao filtro) abriu apenas uma delas, o que impediu a passagem da água necessária à troca térmica na cuba do mancal combinado.	Knowledge; mistake; **Biased reviewing** Cognitive - Remember One step is not realized. action; plan correct action incorrect; omission
077		10,00MW	No dia 27/07/2004, às 16h16minh, horário operacional, foi dado comando de parada indevido do 06G2 na UFL. No momento da ocorrência, o operador tentava dar um comando de parada total no 06G1 para possibilitar a parada das bombas de óleo do regulador de velocidade e, indevidamente, comandou a parada do 06G2 ocasionando o desligamento da máquina	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
078		108,00MW	Logo em segunda foi retirado a excitação sem transferir as cargas de o serviço auxiliar da usina.	Knowledge; mistake; **Biased reviewing** Cognitive - Remember One step is not realized. action; plan correct action incorrect; omission
079		58,00MW	Durante a realização da manobra de transferência do serviço auxiliar 01G3 da barra NORMAL para barra de EMERGENCIA, foi aberto o disjuntor de alimentação da barra normal antes de transferir as cargas auxiliares do 01G3 para barra de emergência. Como conseqüência, houve a atuação da supervisão de mínima tensão provocando parada parcial da unidade.	Skill; slip; **Reversals** Cognitive - Remember Step execution is out of order planned. inversion sequence
080		3,50MW	Abertura acidental do disjuntor 12D1 da SE-PIC, logo após manobra para liberação do disjuntor 12L1	Skill; slip;

			realizada por telecomando, quando da ação do operador em colocar a chave de comando (giro-pressão-giro) do primeiro, em concordância com a posição fechado.	**Perceptual confusion** Perceptive - Identify action; plan correct action incorrect
081		11,70MW	o operador auxiliar pegou o cartão de sinalização para trabalhos em linha energizada da mão do supervisor do turno e deslocou-se para o painel do referido disjuntor, fim realizar manobra. Contudo, ele acionou a chave 52CS, abrindo indevidamente o disjuntor 12J2, em vez de desativar a 79CS, conforme solicitado.	Skill; slip; **Perceptual confusion** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
082		55,78MW	Desligamento automático do Disjuntor 14T4 desenergizando o trafo 04T4 da SE BNO, por jumper acidental, quando o SPCP em conjunto com a DECS, conectava fiação em pontos energizados de o relé auxiliar 893DX em 250 Vcc pertencente ao circuito da chave seccionadora de 230 kV, 34T4 -6 da SE Bom Nome, em função da obra de energização do Trafo 04T5 em paralelo ao Trafo 04T4 na referida SE.	Skill; slip; **Perceptual confusions** Motor - Move action; plan correct action incorrect
083		70,00MW	O desligamento acidental dos disjuntores 14G2 e 13T2 teve como causa fundamental a não identificação de qual das fontes era a defeituosa, e comandar indevidamente a botoeira de rearme de outra fonte que se apresentava com seu funcionamento normal.	Skill; lapse; **Perceptual confusion** Cognitive - Remember Failure to memorize the actions and/or objects. memory; plan correct action incorrect
084		220,00MW	Desligamento automático do gerador 01G1, devido atuação do sistema anti-incêndio do gerador por quebra involuntária do vidro de acionamento de emergência do CO2 quando a equipe de manutenção elétrica realizava atividade de troca de lâmpadas fluorescentes próximo ao air-housing do gerador.	Skill; slip; **Perceptual confusions** Motor - Remove action; plan correct action incorrect
085		31,80MW	Operação indevida da chave 34N2-2, ao ser fechada. A manobra correta seria abrir a chave 34N1-2	Skill; slip; **Perceptual confusion** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection

086	2005	87,00MW	Um dos funcionários que se encontrava junto a chave 32T1-4 limpando os pincéis utilizados na pintura, vendo que a parte superior desta chave não havia sido pintada conforme a 32t1 -5 e 32T1-6 pois não estava na programação e com um lado energizado, decidiu por iniciativa própria subir na chave para pintá-la,	Rule; mistake; **Encoding deficiencies** Cognitive - Decide Failure to memorize the actions and/or objects. memory; plan correct action incorrect
087		15,00MW	A falha humana foi cometida pela não confirmação no pátio da chave 32T1-5, tendo a mesma ficado mal fechada, devido quebra da haste de acionamento	Rule; mistake; **Countersigns and nonsigns** Perceptive - Identify One step is not realized. action; plan correct action incorrect; omission
088		151,00MW	Durante a realização da manobra de liberação da chave 35L4-8 da SE CMD, a operação da subestação realizou o fechamento manual indevido de um pólo da chave 35T1-7ª, provocando curto-circuito monofásico à terra, que acarretou a atuação das proteções do transformador 05T1 e seu isolamento pela abertura dos disjuntores 15T1, 14T1-A e 14T1-B.	Skill; lapse; **Perceptual confusions** Perceptive - Identify Failure to memorize the actions and/or objects. memory; plan correct action incorrect
089		1,90MW	No dia 22.02.2005, às 12:58h, horário operacional, ocorreu o desarme automático do gerador 06G1da UFL por atuação da proteção de Baixa Pressão 2º Grau do Balão Ar + Óleo do Sistema de Regulação de Velocidade. A perda de pressão foi motivada pelo desligamento manual da bomba No 1 do Sistema de Regulação de Velocidade, quando a bomba No 2 desse mesmo sistema não conseguiu manter a pressão do Balão Ar + Óleo, devido à existência de inversão remota da seqüência de fases da alimentação do seu motor.	Knowledge; mistake; **Confirmation bias** Cognitive - Remember The operator doesn't have ready rules, than He improvises new rules. Plan; plan incorrect.
090		15,00MW	No dia da intervenção (16/10/2005), foram realizadas todas as adequações necessárias conforme planejamento, porém durante a colocação dos relés de TRIP para normalização dos circuitos de MPCC e entrega dos trabalhos a operação, no momento da colocação do último relé (50/51 – X4) em sua base, houve a atuação de alguns contatos, normalmente abertos, nesta ação, ocasionando a aberturas automática dos disjuntores 12C1/12C3/12C4/12C5.	Skill; slip; **Perceptual confusions** Motor - Move action; plan correct action incorrect
091		8,60MW	O CROO solicitou a abertura do disjuntor 12J1 na SE-SJI visando desenergizar a LT-02J1(SJI/ SJP) a pedido da CEPISA. O OPE da SE-SJI procedeu a abertura indevida do disjuntor 12J2(SJI/ ELM). Logo que percebeu o erro, efetuou o fechamento do disjuntor 12J2 e em seguida a abertura do disjuntor 12J1.	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
092		58,00MW	Durante a realização da manobra de transferência de alimentação da barra de EMERGENCIA, foi aberto o disjuntor CG1-4 ao invés de fechar o CG1-5, para o CG1-4 abrir automático, desenergizando a barra de	Skill; slip; **Perceptual confusions**

			emergência provocando o desligamento automático da unidade 01G4 devido atuação da supervisão de mínima tensão provocando parada total da unidade.	Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
093		32,00MW	Descumprimento da seqüência de manobras, por parte do OPI, constante da IO-BJS.01	Skill; slip; **Reversals** Cognitive - Remember Step execution is out of order planned. inversion sequence
094		66,00MW	Às 10h50 , iniciou-se os testes no chassi de proteção CH5, quando deveria ser no QRAs,	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
095		85,00MW	Esta atuação incorreta das proteções diferenciais dos transformadores 04T1 e 04T2 da SE PCD, foi uma repetição das atuações incorretas destas mesmas proteções, para o mesmo defeito externo ocorrido no dia 07/11/2005. Após da ocorrência do dia 07/12 e a conseqüente detecção do problema, a DOPR recomendou em caráter de urgência ao SNCP, a implantação de novos ajustes nos relés 7UT51 dos transformadores 04T1 e 04T2 da SE PCD.	Knowledge; mistake; **Biased reviewing** Cognitive - Compare One wrong rule was applied correctly plan; plan incorrect
096		85,00MW	Para evitar atuações das proteções diferenciais utilizadas nos transformadores 230/69 kV da SE PCD, para faltas monofásicas externas à zona diferencial, deve-se eliminar da medição do relé, a contribuição de seqüência zero (3I0) dos neutros dos transformadores. Como proteção dos transformadores 230/69 kV da SE PCD, são utilizados relés 7UT51, da Siemens, onde a eliminação da corrente 3I0 é realizada através de ajuste, pela ativação da função "I0 elimination". Este ajuste foi considerado de forma correta no estudo de graduação, no entanto, a Ordem de Ajuste (AO) foi emitida de maneira incorreta, por engano, deixando a função desativada.	Rule; mistake; **Encoding deficiencies** Cognitive - Decide One wrong rule was applied correctly plan; plan incorrect
097		129,00MW	O desligamento foi resultado de uma falha no projeto e parametrização do relé 7SJ531 do lado de 230kV do ATR 05T1 da SE MLG, na época da obra, e que não foi percebida pela DOPR quando definiu com urgência as providências a serem tomadas para re-energização do ATR sem o TPC da fase C do lado de 230kV.	Rule; mistake; **Encoding deficiencies** Cognitive - Compare One wrong rule was applied correctly plan; plan incorrect
098		66,13MW	O desligamento foi resultado de uma falha na verificação da seletividade entre as proteções da LT 02J4, Santo Antônio de Jesus/Nazaré-02J4 e do trafo 04T1 da SE Santo Antônio de Jesus, devido a utilização de diagrama de tempos de operação de proteções referentes ao ajustes anteriores da proteção do transformador, levando à conclusão errônea de existência de seletividade.	Rule; mistake; **Encoding deficiencies** Cognitive - Compare One wrong rule was applied correctly plan; plan incorrect

099	2006	102,00MW	Inexistência de procedimento adequado e normatizado de inspeção, controle da poluição e de lavagem do isolador tipo multicorpo em função de suas características de isolamento (alto valor da distância de escoamento).	Rule; mistake; **Rule strenght** Cognitive - Decide The operator doesn't have ready rules, than He improvises new rules. Plan; plan incorrect.
100		269,90MW	Durante as manobras de liberação do disjuntor 14M4 para manutenção, a operação da subestação abriu indevidamente o disjuntor 14D1, ao invés do 14M4, com a posterior abertura da chave 34M4-1 em carga, provocando curto-circuito monofásico à terra no barramento 04BP-1 e o conseqüente desligamento automático da SE CTU, com interrupção de carga da ordem de 269,6MW.	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
101		1,40MW	No dia 08 / 06 / 2006, às 14h56minh, horário operacional, durante manobra de normalização do religador 21Y4 que estava liberado para manutenção preventiva, o operador da UFL comandou a abertura do 21Y5 em vez do 21D1, ocasionando a interrupção de 1,4MW durante 1 minuto e 9 segundos do alimentador 01Y5 que supre as cargas da cidade de Ubatã-BA.	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
102		6,00MW	A equipe verificou nos desenhos operacionais, que uma das condições de se ter um trip direto para o disjuntor seria através do relé 62X, que faz parte do esquema de alívio de carga que se encontra fora de operação. Logo foi realizado um jumper nos contatos 1 e 2 do referido relé 62X, conforme desenhos da SE, para verificar a identificação de alguma falha no circuito de trip do 12J1, porém a equipe não atentou para o detalhe que, a chave na posição 43T transfere os trip dos esquemas especiais para o disjuntor 12D1, onde ocorreu a abertura do 12D1 que substituía o 12J1.	Knowledge; mistake; **Biased reviewing** Cognitive - Remember Failure to memorize the actions and/or objects. memory; plan correct action incorrect
103		1,00MW	Quando chegou o momento do OPI Auxiliar abrir a Chave de Interligação 31B2-1 (Conforme RTM, Item 2.6), o mesmo abriu indevidamente a Chave de Entrada 31T7-9, desenergizando a LT 01Y1.	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
104		24,6MW	Em torno das 18h00min h, foi observado pelo OPI do turno seguinte ao da ocorrência, que a chave 43V3 de transferência de proteção do 12V3 encontrava-se indevidamente na posição **'T' Transferido**, quando deveria está na posição **'N' Normal**, causa provável, por analogia, da ocorrência.	Skill; slip; **Perceptual confusions** Perceptive - Observe Wrong object selected due similarity with

				desirable object. action; plan correct, action incorrect; wrong selection
105		20,00MW	Durante a retirada de uma tampa de canaleta neste painel PCC13 ocorreu toque não intencional com conseqüente abertura do disjuntor 52-1	Skill; slip; **Perceptual confusions** Motor - Remove action; plan correct action incorrect
106		5,00MW	Desligamento automático da LT 03C1-Barreiras/Rio Branco quando da tentativa de religamento manual por solicitação do Operador do CROP. O OPS comandou o religamento manual da referida LT sem a autorização do Operador do COS da COELBA, estando a mesma aterrada sem conhecimento do CROP.	Rule; mistake; **Action deficiencies** Cognitive - Decide Step execution is out of order planned. inversion sequence
107		126,57MW	A atuação acidental da proteção 51V do lado de 138kV do trafo 04T1 deveu-se a falha na elaboração da nova OA corrigindo a versão do relé URP 2402 para 1.00, o qual não possui bloqueio para tensões acima do valor de restrição, mantendo o mesmo valor de pick-up da OA anterior que considerava a versão 2.02, um pouco abaixo da carga máxima.	Knowledge; mistake; **Biased reviewing** Cognitive - Compare One wrong rule was applied correctly plan; plan incorrect
108		68,00MW	A atuação da proteção de sobre corrente de neutro do transformador de aterramento 02A1, da barra de 69kV da SE Pau Ferro, para defeito monofásico, fase C/T, localizado no TP do barramento de 69kV da SE Sec. Pau Ferro, da CELPE, externo à sua zona de proteção primária, deveu-se a falha na elaboração das Ordens de Ajustes dos relés de sobre corrente de neutro temporizados, 7SJ6225, da Siemens, das LT 02N5/02N6, Pau Ferro/Sec. Pau Ferro, na SE Pau Ferro.	Knowledge; mistake; **Biased reviewing** Cognitive - Compare One wrong rule was applied correctly plan; plan incorrect
109		32,00MW	No decorrer da execução das atividades de comissionamento da Unidade de Terminal Remota, UTR, a ser instalada nesta Subestação, como parte integrante do projeto SINOCON, a equipe técnica terceirizada da Empresa CEMONTEX, tocou acidentalmente em dois condutores do esquema de falha do disjuntor de transferência da barra de 69 KV, que se encontravam soltos, isolados por fita crepe, resultando no desligamento da barra da SE IRE e de todas as linhas de transmissão e 69 KV .	Skill; slip; **Perceptual confusions** Motor - Move action; plan correct action incorrect
110	2007	99,76MW	**Causa fundamental** – descumprimento de procedimentos normatizados pela NM-TCPA-EM-012 – *Intervenção para pesquisa de fuga dc à terra*, na execução de atividade de alto risco, sem o planejamento adequado.	Knowledge; mistake; **Overconfidence** Cognitive - Decide The operator doesn't have ready rules, than He improvises new rules. plan; plan incorrect.
111		98,41MW	**Causa Fundamental**: desconhecimento por parte da equipe de manutenção da existência de relés eletromecânicos internos aos relés eletrônicos, capazes de atuar na presença de vibração intensa, como ocorreu durante o corte do chassi de proteção do trafo de terra.	Rule; mistake; **Encoding deficiencies** Information - Request The operator don't have ready rules, than He improvises new rules. plan; plan

				incorrect.
112		3,20MW	Abertura do 12L4, face acionamento inadequado da chave 101-12L4, quando da tentativa de concordar a posição da referida chave, no painel, com o estado do disjuntor.	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
113		45,91MW	Os desligamentos ocorridos na SE Santa Cruz II, no dia 29/04/07, foram causados por uma seqüência de erros não detectados nos processos de pré-operação, programação de manobras e execução em tempo real, impactando em todo o processo de gerenciamento de intervenções do CROL.	Rule; mistake; **Encoding deficiencies** Cognitive - Compare One wrong rule was applied correctly plan; plan incorrect
114		4,00MW	Desligamento acidental do disjuntor 12M1 SE MDR quando a equipe SPCP efetuava colocação da tampa da proteção de sobre corrente IACE-11B2 fase C, em virtude do contato acidental da tampa com o borne B da bobina ISC provocado por falha humana.	Skill; slip; **Perceptual confusions** Motor - Move action; plan correct action incorrect
115		53,00MW	Desligamento acidental da LT 03C2 BNO/CBB durante as atividades de implantação dos novos painéis de controle de paralelismo (PCPs) dos trafos 04T4/04T5, provocado por aterramento acidental e conseqüente queima do fusível da fase B do TP 83C	Skill; slip; **Perceptual confusions** Motor - Move action; plan correct action incorrect
116		10,00MW	Desarme do disjuntor 13T3, desenergizando LT 03C1, quando o técnico da equipe de manutenção do SBMS inseriu o relé k2, do circuito de abertura do referido disjuntor que se encontrava fechado (configuração normal). Este fato ocorreu, após a devolução da intervenção pelo responsável, do SBCP, que, na ocasião, não havia percebido a ausência do relé K2, retirado durante os trabalhos para investigação de defeito fuga à terra, que vinha provocando a saída intempestiva da LT 03C1, registrada por 03 (três) vezes, entre os dias 22/11 e 26/11.	Skill; slip; **Reversals** Motor - Move Step execution is out of order planned. inversion sequence
117		26,00MW	A atuação da proteção de sobre corrente das fases A/B do disjuntor 12T3 da SE Bom Nome, para defeito bifásico, externo à sua zona de proteção primária, deveu-se a falha durante a fase de elaboração dos Estudos Elétricos.	Knowledge; mistake; **Biased reviewing** Cognitive - Compare One wrong rule was applied correctly plan; plan incorrect
118		23,53MW	Desligamento automático da LT 03M2 CRD/STD e abertura automática da LT de 138kV 03C1 SMD/CRD na SE SMD, coincidente com um curto trifásico na LT 03M2 CRD/STD, próximo da SE STD, provocado por descarga atmosférica, desenergizando as SE's SMD e CRD. A LT 03M2 CRD/STD desligou pela atuação da proteção 21 em ambos os terminais, sendo em 1ª zona no terminal de STD e em 2ª zona no terminal de CRD. Na SE SMD, o terminal da 03C1 abriu pela atuação da proteção 67 A/C.	Knowledge; mistake; **Biased reviewing** Cognitive - Compare One wrong rule was applied correctly plan; plan incorrect
119		23,10MW	A atuação da proteção de sobre corrente de neutro do disjuntor 12T3, da SE Bom Nome, para defeito externo	Knowledge; mistake;

			à sua zona de proteção primária, deveu-se a falha durante os Estudos Elétricos dos relés de sobre corrente de neutro temporizado, 12IAC-53B da General Eletric, da LT 02V2 Bom Nome / Flores, quando da elevação do limite base de proteção desta linha de transmissão. É imprescindível uma análise minuciosa da configuração da instalação através do diagrama operacional durante os Estudos Elétricos, a fim de evitar erros que provoquem desligamentos.	**Biased reviewing** Cognitive - Compare One wrong rule was applied correctly plan; plan incorrect

120	2008	4,80MW	A causa principal dessa ocorrência deveu-se a “falha de atenção” no processo de montagem, comissionamento e integração da referida LT.	Rule; mistake; **Action deficiencies** Perceptive - Observe Failure to memorize the actions and/or objects. memory; plan correct action incorrect
121		14,00MW	No dia 11/11/2008 às 10h48min, durante manobras de transferência do disjuntor 12J7 executados pela Operação, com os disjuntores 12J7 e 12D1 fechados, e com a chave 43T (seletora de transferência) na posição ET (em transferência), ocorreu abertura indevida do 12D1, sem sinalização de proteção, quando foi realizado comando de abertura do disjuntor 12J7, para a complementação da configuração de transferência.	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
122		1,16MW	Durante solicitação da concessionária COSERN para desativar o religamento automático do 21C2 da SE CRD, o CROL efetuou o telecomando de abertura do 21C2 quando deveria ter telecomandado a desativação do religamento automático do mesmo, acarretando interrupção nas cargas do alimentador 01C2, 1,16MW, por um período de 8 segundos.	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
123		37,63MW	O operador deu o comando de abertura na chave 34M1-1 pensando ter dado o comando de abertura na chave 34M1-2	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
124		38,00MVar	A Equipe de Manutenção deixou de rever o Planejamento da Intervenção diante de um novo cenário surgido face à identificação da origem do vazamento de óleo isolante no Reator 01E9.	Knowledge; mistake; **Confirmation bias** Cognitive - Compare The operator don’t have ready rules, than

				He improvises new rules. plan; plan incorrect.
125		3,67MW	No dia 21/05/08, às 10h08min, a equipe técnica de operação realizava manobras para liberação do disjuntor 01Y1. Houve perda da barra 01BP e 01B4 decorrente atuação indevida do esquema de falha do disjuntor associado ao disjuntor 11Y1 com a abertura do disjuntor 11BP, decorrente inversão de circuito de fiação associado ao 11Y1 atuado o esquema de falha de disjuntor. A referida inversão foi decorrente a uma implantação antiga que não foi detectada pela DOMC durante o comissionamento do projeto SINOCON.	Rule; mistake; **Encoding deficiences** Cognitive - Compare One wrong rule was applied correctly plan; plan incorrect

126	2009	9,64MW	durante a realização de manobras para normalização do religador 21Y5, que estava transferido e entregue à manutenção, foi aberto indevidamente o disjuntor geral 11W1 em vez do 11D1, desenergizando o barramento 01B2.	Skill; slip; **Perceptual confusions** Perceptive - Identify Wrong object selected due similarity with desirable object. action; plan correct, action incorrect; wrong selection
127		24,92MW	A causa da operação do relé de bloqueio foi o contato acidental de potencial positivo com o seu borne de atuação, provocado quando a equipe de manutenção realizava a retirada da fiação desativada do chassi de proteção, isolada com fita crepe.	Skill; slip; **Perceptual confusions** Motor - Remove action; plan correct action incorrect
128		750,50MW	Às 10h29min dia 08/10/2009, ocorreu o desligamento da BARRA PRINCIPAL 69KV (02BP) da SE MRR, provocada pela abertura em carga da chave 32J4-5, devido a acidente durante deslocamento do equipamento "SKYLADER", para posicioná-lo em situação de realização de trabalho.	Skill; slip; **Perceptual confusions** Motor - Move action; plan correct action incorrect
129		199,00MW	A causa principal do desligamento foi a falha no planejamento, quando não houve a percepção de que haveria atuação do circuito de trip do 02A2, quando da realização do comando de abertura do 12D1 com a manutenção da adequação provisória e a ativação do circuito de trip do 02A2. Por se tratar de uma atividade de urgência, o planejamento e a análise das atividades f oram feitos simultaneamente à execução. Mesmo não sendo esse o fator fundamental para a causa do desligamento, é possível que, com mais tempo para análise e maturação da configuração provisória, poderiam ter sido evitadas as falhas do planejamento e, conseqüentemente, o desligamento.	Knowledge; mistake; **Biased reviewing** Cognitive - Compare One wrong rule was applied correctly plan; plan incorrect
130		15,10MW	As equipes envolvidas na intervenção realizaram análise dos testes a serem realizados, no entanto, não foi visualizado o risco de atuação do esquema de falha do disjuntor 12T5, pelo fato de que o único contato normalmente aberto da chave 86-T5, utilizado no projeto de proteção e controle, não tem a função direta de desligamento do disjuntor 12T5.	Knowledge; mistake; **Biased reviewing** Cognitive - Compare Failure to memorize the actions and/or objects. memory; plan correct action incorrect
131		9,96MW	Após conclusão das atividades de substituição da bucha do transformador 04T1 da SE CCD, ocorrida em	Skill; slip;

			02.08.2009, no período das 09 às 12h00min, foi devolvido o equipamento à Operação, conforme previsto, sendo energizado às 12h 04 min. Às 12h07min, ocorreram os desarmes dos disjuntores 14W1 e 12M1, através da chave 86 T, motivado devido à válvula de segurança do transformador 04T1 encontrar-se atuada. Às 12h12min, após inspeção no equipamento, foi constatado a válvula que a segurança estava atuada.	**Reversals** Cognitive - Remember One step is not realized. action; plan correct action incorrect; omission