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# Safety Function Analysis in an Industrial Production Process

Dissertação para obtenção do Grau de Mestre em
Engenharia e Gestão Industrial

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# Resumo

*Objetivo:* Este trabalho teve como objetivo identificar e avaliar aspetos de segurança numa linha de produção de uma empresa transformadora de papel chamada Renova. A avaliação contemplou fatores técnicos e também fatores organizacionais e de gestão. O estudo foi realizado através da avaliação de funções de segurança (FS), presentes ou não, no sistema produtivo. *Métodos*: Para a realização do estudo foi aplicada uma versão nova e mais recente do método SFA (*Safety Function Analysis*), desenvolvido por Harms-Ringdahl, primeiro em 2001 e mais tarde em 2011, ainda em rascunho. Esta metodologia foi aplicada em dois processos ("*raw material loading"* – carregamento de matéria-prima e "*transversal cut of log"* – corte transversal de charuto) de uma linha de produção (H4) da empresa referida. *Resultados*: No primeiro processo analisado (carregamento de matéria-prima), foram identificadas e avaliadas 47 funções de segurança; o segundo processo (corte transversal de charuto) consubstanciou 36 funções de segurança. A maioria das funções de segurança avaliadas apresenta boas condições de funcionamento e monitorização adequada; por isso não necessitam de quaisquer melhorias. No entanto, foram também encontrados casos que necessitam de melhorias essenciais. *Conclusões*: Como consequência da análise realizada com o método SFA, foram feitas recomendações concretas ao nível da segurança, de forma a melhorar o desempenho geral do sistema; sendo uma fábrica de transformação de papel, é importante a implementação de testes termográficos que possibilitem identificar pontos quentes, suscetíveis de originar focos de incêndio.

Palavras-Chave: *análise de segurança, função de segurança, método SFA, indústria de papel*

# Abstract

*Aim*: The purpose of this work was to identify and assess safety features on a production line of paper manufacturer called Renova. The assessment includes technical as well as organisational factors. The study was carried out through the evaluation of safety functions (SF), either present or absent in the system analyzed. *Methods*: The methodology applied was the SFA (Safety Function Analysis), which was developed by Harms-Ringdahl in 2001 and was updated further, in 2011 (draft version). The analytical framework was applied in two processes (*raw material loading* and *transversal cut of log*) of a production line (Line H4) of Renova. *Results*: In the first process analyzed (*raw material loading*), 47 safety functions (SF) were identified and evaluated, whereas 36 SF were assessed in the second case (*transversal cut of log*). The evaluation has shown that most of the SF considered are in good condition and being well monitored, therefore they do not need any improvements. In contrast, this work has also identified a number of safety functions that need essential improvements. *Conclusions*: As a consequence of this SFA analysis, the author proposes a number of specific recommendations to improve safety and the system's performance in general. Since Renova is a manufacturer of paper products, fire safety is of paramount importance and one of the most relevant recommendations is perhaps the implementation of thermo graphic tests to identify possible hot spots that may originate a fire.



Keywords: *safety analysis, safety function, SFA method, paper manufacturing.*

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# Acronyms and Abbreviations

| | |
|---|---|
| ADM | Administration |
| AGV | Automated Guided Vehicle |
| CS | "*Comissão de Segurança*" - Safety Commission |
| DIFA | "*Divisão de Fabricação*" -Fabrication Division |
| DIRE | "*Divisão de Reciclagem*" - Recycling Division |
| DISA | "*Divisão de Produtos Sanitários*" - Sanitary Product Division |
| DITA | "*Divisão de Transformação*" -Transformation Division |
| DMRA | Decision Matrix Risk-Assessment |
| EMAS | Eco-Management and Audit Scheme |
| ETA | Event Tree Analysis |
| FTA | Fault Tree Analysis |
| HAZOP | Hazard and Operability Studies |
| JSA | Job Safety Analysis |
| PEA | Predictive, Epistemic Approach |
| PEI | "*Plano de Emergência Interno*" – Internal Emergency Plan |
| PRAT | Proportional Risk-Assessment Technique |
| RAA | Risk Analysis and Assessment |
| RBM | Risk-based Maintenance |
| RGS | "*Responsável pela Gestão de Segurança*" - Responsible for the Safety Management System |
| RSS | "*Responsável pelos Serviços de Segurança*" - Responsible for Safety Services |
| SF | Safety Function |
| SFA | Safety Function Analysis |
| SHST | "*Serviços de Saúde e Segurança no Trabalho*" – Health and Safety at Work Services |
| STS | "*Serviços Técnicos de Segurança*" – Technical Security Services |

# 1. **Introduction**

Safety at work can be supported by several analytical and practical approaches. However, when talking about safety one must refer to risk too, once risk and safety are linked both conceptually by comparing definitions, and pragmatically through its reciprocity, since a higher level of safety its equivalent to a lower level of risk.

There is an increased need to improve safety along the passing years, and such need requires methods to explore/examine workplaces, machinery, processes, and even entire factories if needed. All the methods must contribute to the risk elimination or the reduction of consequences, through hazard identification and safety improvement.

The Energy model, for instance, is one of the many approaches for the analysis of safety characteristics, in which “defense” and “barrier” are general concepts that represent several types of safety features. In a general and simple way, the defenses should prevent hazards from causing losses. This method, like many others, usually involves technical and organizational barriers. This term, as well the term “safety barrier”, is frequently used in risk assessment literature. Hollnagel (2008) describes them as being physical or non-physical obstacles that can be created to prevent unwanted events, or protect them from more serious consequences.

A new methodology to risk assessment was created by Harms-Ringdahl from 2000 (Harms-Ringdahl, 2001, 2003a, 2003b); it is based on the study of safety functions identified within a certain hazard. This methodology is known as *Safety Function Analysis* (SFA). The method is generic and can be applied to most types of systems or events; however when assessing safety, it is considered as a specific evaluation, once only the most significant hazards, previously identified by traditional methods, are included in a SFA study.

The objective of this work is to study the safety level of an industrial process by applying a new version of the SFA method referred above and also to test the application of this new version. In 2011, a new development of the method was made by Harms-Ringdahl; it has some improvements and new steps which are going to be described later in more detail. The author of this thesis applied the new version in a production line of paper, located in Renova. This study resulted from a need of the company to analyze and improve the safety features of a particular production line; the referred line is quite long and involves a range of possible hazards. Another aspect that motivated the application of this particular approach is the fact that the older version of SFA had been applied in the same company in 2009 (Carracinha and Jacinto, 2009).

This thesis is structured in seven chapters, which will be shortly described below.

The second chapter presents a summary of the theoretical and practical framework, splitting it into two topics. In the theoretical topic, the literature review is divided in three parts, related to risk analyses and safety analyses. There are important concepts discussed, such as risk definitions in the first part, and the different notions of "Barriers" addressed to "Safety Functions" in the second part. The third part of this literature review refers to some different methods used in "*Risk Analyses*" and "*Safety Analyses*" where the Safety Function Analysis (SFA) method is briefly introduced. The practical topic refers to the legal requirements applicable to the case study presented in this work, namely the machinery and the use of equipment directives. These legal requirements set the starting point to identify the safety functions used in the checklists of the SFA method.

In the third chapter the author describes the methodology of this work. It is described the original version of the SFA method (2003) and its six phases of implementation, suggested by Harms-Ringdahl. Then, the new version of the method is presented together with its differences from the original. For better understanding it will be presented a flowchart that highlights the differences between the two versions of the SFA method. These differences will be explained in more detail, one by one, regarding its application in the case study.

The host company (Renova) of this work is presented in chapter four, with a short characterization of its productive processes. The chosen process for the case study, where the SFA method is applied, is described in detail too.

Chapter five describes the application of the SFA method, and how its five stages (new version) are applied step-by-step using two illustrative case studies, whereas Chapter six presents and discusses the most significant results.

The seventh and last chapter summarizes the most relevant conclusions of this work, referring the main advantages and disadvantages of this new version of SFA and the possible added value given to Renova by using these results to their benefit.

# 2. State of the art (theory and legal issues)

In this chapter important concepts will be discussed to facilitate understanding of the work. When doing this it is important referring to both theoretical and practical issues, such as the literature review and the not least important, legal requirements. This chapter is structured into two topics so it can be explained in more detail.

## 2.1 *Literature Review*

The first topic embraces the most theoretical aspects of scientific literature in this domain; it will approach three main points regarding work safety: risk analysis, safety analysis and methods; which will be explained next.

### 2.1.1 Risk Analysis

Within an industrial plant, one can either talk about industrial (operational) or occupational risks. This work is more focused on occupational risk, but it also takes into account industrial risk such as fire and explosion, handling of substances hazardous to health and environment or even risk of chemical release.

The definition of risk has been changing over the years, so it is not easy to find one universal definition. When the word risk is used, it concentrates the effects of change as well as the difficulty to predict it. Villemeur, for instance, defines risk as a "*hazard measure combining a measure of the occurrence of an undesirable event and a measure of its effects or consequences.*" *(Villemeur, 1992; p.708).*

Associated with any general definition of risk are two fundamental factors: the probability of occurrence and the gravity level of the consequence. This relation is illustrated in figure 2.1.

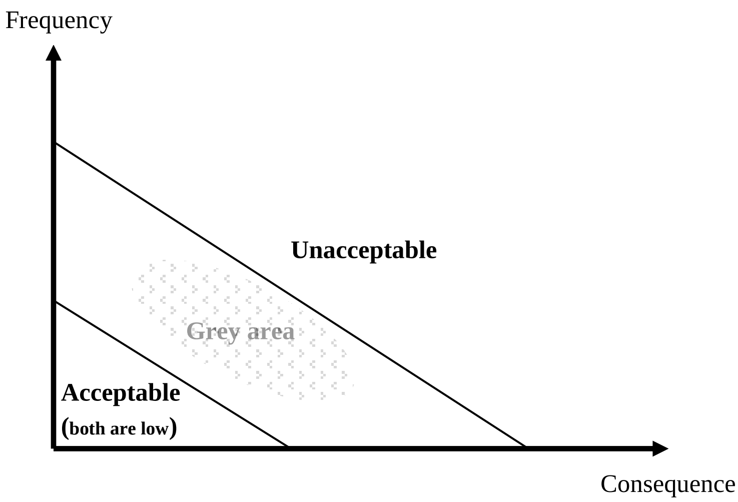


**Figure 2.1 - Relation between frequency and consequence (adapted from Harms-Ringdahl, 2001, p. 46)**

For example, in the *acceptable* zone the risk is below the limits of acceptance; it means that there is both low probability of occurrence and small consequences if an accident occurs. On the other hand, in the *unacceptable* zone, there is a high probability of occurrence and serious consequences if an accident takes place; it means that urgent measures must be taken to reduce the probability and/or the gravity level. The *grey area* zone of the risk is a complicated issue, especially in large and complex systems. It can be applied the ALARP (As Low As Reasonably Practicable) principle, which means that the best that can be done under prevailing circumstances must be done.

Numerical quantified estimates are difficult to classify risk and it takes quite an effort. So, a common approach is to classify risks according to consequences and their frequency of occurrence; however this is a qualitative assessment, or at most a semi-quantitative one, since it returns estimated results instead of definitive values, and is based on people's judgments. Table 2.1 provides an example of a scale for consequences and probability values.

**Table 2.1 - Scale for consequences and probability values (adapted from Harms-Ringdahl, 2001, p. 48)**

| **Consequences** | | **Probability** | |
|---|---|---|---|
| **Code** | **Category** | **Code** | **Category** |
| **0** | Not harmful or trivial | 0 | Once a week |
| **1** | Short period of sick leave | 1 | Once a month |
| **2** | Long period of sick leave | 2 | Once a year |
| **3** | Disablement | 3 | 1 in 10 years |
| **4** | Fatality | 4 | 1 in a 100 years |
| **5** | Several fatalities, major disaster | 5 | 1 in a 1000 years |

When addressing *occupational safety and health*, in particular, the definitions more commonly used are standardized as follows:

***Hazard***: source, situation, or act with a potential for harm in terms of human injury or ill health, or a combination of these (OHSAS 18001, 2007, p.2)

***Risk***: combination of the likelihood of an occurrence of a hazardous event or exposure(s) and the severity of injury or ill health that can be caused by the event or exposure(s) (OHSAS 18001, 2007, p.4)

***Risk assessment***: process of evaluating the risk(s) arising from a hazard(s), taking into account the adequacy of any existing controls, and deciding whether or not the risk(s) is acceptable (OHSAS 18001, 2007, p.5)

In short, when straightening the concept to occupational risk, it refers to the likelihood and severity of an injury or an illness to take place as a result of exposure to a hazard, being "hazard" something that has the potential to cause harm to people.

A recent paper from Marhavilas et al (2011) states that "*risk analysis and assessment (RAA) techniques are classified into three main categories: (a) the qualitative, (b) the quantitative, and (c) the hybrid techniques (qualitative-quantitative, semi-quantitative)*" (Marhavilas et al, 2011, p.478). The qualitative techniques (Check-lists, Task Analysis, HAZOP, etc) are based on analytical estimation processes and on the safety managers/engineers ability. As for the quantitative techniques (PRAT technique, DMRA technique, PEA method, etc), risk can be estimated and expressed by a mathematical relation, using real accident data, recorded in a work site; in this case, as the name suggests, the risk can be considered as a quantity. The hybrid techniques (FTA, ETA, RBM, etc) are usually very complex and have sometimes an *ad hoc* nature, which may prevent their wide use. These authors' review (Marhavilas et al, 2011), covering the decade 2000 to 2009, conclude that papers with RAA techniques still constitute a very small part of the scientific literature.

### 2.1.2 Safety Analysis

In practice, the concepts of risk analysis and safety analysis are complementary to each other. If one considers, by analogy, that a scale from 0 to 1 is used, with a risk level around 0.3, this means that the safety level is around 0.7. What changes is the way one looks at the phenomena: either by the risk side, or by the safety side.

**Barriers**

Harms-Ringdahl (2001, 2003a, 2003b, 2004) states that some authors use the term barrier to identify organizational aspects, while others use terms such as: barrier function; defense or protection layer. Hollnagel (2004) characterizes the term barrier as prevention or protection; they can be used before or after the action takes place in time regarding the prevention or the protection. There are different concepts and terminology related to the term barrier as the ones given by Harms-Ringdahl and Hollnagel.

Other possible classifications are active barriers or passive barriers. Active barriers imply the need to do a certain safety function, while passive barriers have any defined action, but their simple presence in a system is the function. Hollnagel (2004) classify the active barriers as permanent or temporary; where permanent barriers are normally included in the project phase, while temporary barriers are used in timely situations such as occasional workout.

Therefore barriers can be considered as being an "obstruction" to prevent a dangerous action, or if it can't be prevented, to minimize the possible consequences by protecting people, property and/or the environment (Fig. 2.2).

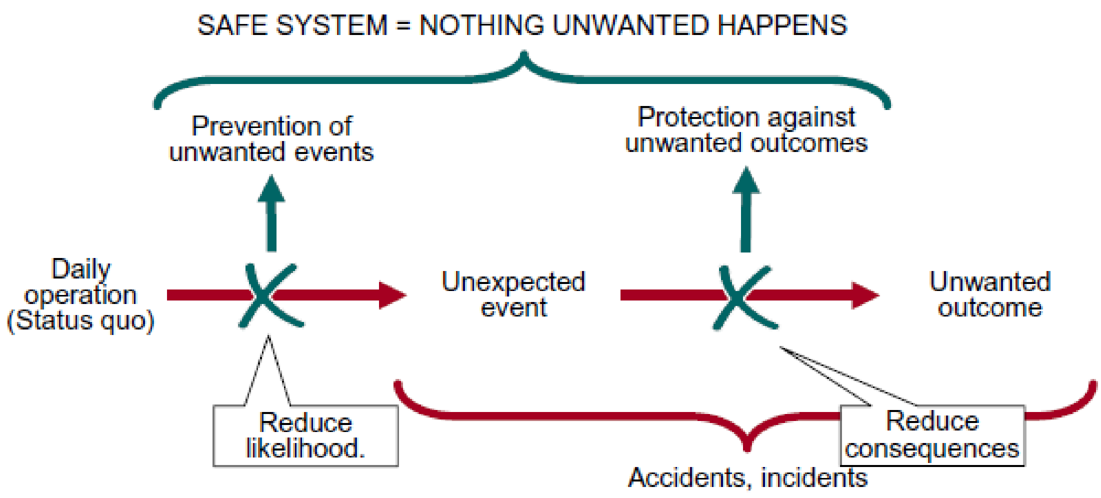


**Figure 2.2 - Safety through prevention and protection (Hollnagel, 2008, p. 222)**

The term safety barrier was firstly used by Gibson in 1961, as result of the application of an energy model (Fig. 2.3) in accident investigation, later by Haddon in 1980, in the subsequent development of the same model, when he presented the ten accident prevention strategies (*c.f.* Sklet, 2006). On the other hand, Hollnagel states that:

*"whereas the barriers used to defend a medieval castle mostly were of a physical nature, the modern principle of defense-in-depth combines different types of barriers—from protection against the release of radioactive materials to event reporting and safety policies."(Hollnagel, 2004, p. 71)*

The safety barriers are critical to reduce the risk of accidents, so that their importance is demonstrated by risk-informed principles and safety barriers in European regulations such as the Seveso II directive (EC, 1996) and Machinery Directives (DL-103/2008).

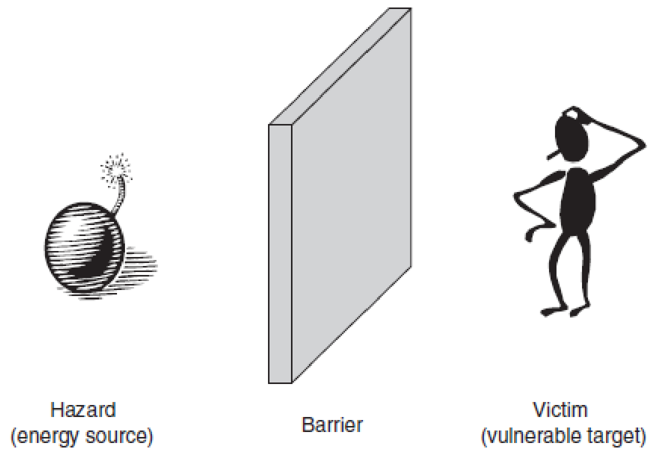


**Figure 2.3 - The Energy model (based on Haddon, 1980; cited by Sklet, 2006b)**

Sklet (2006b) proposes some definitions of Safety Barriers, Barrier Functions and Barrier Systems:

*"A **Barrier System** is a system that has been designed and implemented to perform one or more barrier functions"* (*Sklet, 2006b, p.496).*

It describes how a certain barrier function is executed. A barrier system may consist in different kinds of elements, physical or technical, operational activities performed by people, or the combination of both. There are different manners to classify barrier systems, depending on the authors (e.g.: Hollnagel, 2004, 2008; Sklet, 2006a; Sklet 2006b; Duijm, 2009).

In turn, barrier systems can be characterized by four types of possible barriers (Table 2.2).

Physical barriers are incorporated in the design of the construction; these systems stop an action/event using physical means and can be used against energy, material and people. For example: walls, doors, grids, etc. In general, technical barriers are initiated if a hazard is triggered.

Functional barriers are defined by logical conditions that stop an action to take place in time, meaning that the function needs to meet one or more pre-requirement so the action can be performed. These requirements don't need to be visible or perceptible to an operator; however its presence is indicated (e.g. establishing an interlock, either logical or temporal (*c.f.* Leveson, 1995)).

Symbolic barriers require human comprehension so their meaning can be understood.

Incorporeal barriers are not physically present however its existence must be known by the user in a situation so that they can meet their purpose. Yet, incorporeal barriers are represented through technical books, rules or even laws.

**Table 2.2- Barrier systems and respective barrier functions (Adapted from Hollnagel, 2008, p. 226)**

| Barrier System | Barrier Function | Example |
|---|---|---|
| **Physical** | Contain or protect. | Walls, doors, buildings, filters, containers, tanks, valves, rectifiers, etc. |
| | Prevent transporting something from the present location (release) or into another (intrusion). | Safety belts, harnesses, fences, cages, etc. |
| | Keep together. Cohesion, resistance. | Safety glass. |
| **Functional** | Prevent movement or action (mechanical, hard). | Locks, equipment alignment, physical interlocking, equipment match, etc. |
| | Prevent movement or action (logical, soft). | Passwords, entry codes, action sequences, pre-conditions, physiological matching, etc. |
| | Hinder or impede actions (spatio-temporal). | Distance, persistence, delays, synchronization, etc. |
| **Symbolic** | Counter, prevent or stop actions (visual, tactile interface design) | Coding of functions, demarcations, labels & warnings, etc. |
| | Regulate actions. | Instructions, procedures, dialogues, etc. |
| **Incorporeal** | Comply, conform to | Self-restraint, ethical norms, etc. |
| | Prescribing: Rules, laws, guidelines, prohibitions | Rules, restrictions, laws, etc. |

It is crucial that barriers can fulfill their purpose; therefore there is a set of quality attributes pointed out by Hollnagel (2008) that must be analyzed when referring to the four systems described previously: Efficiency, Resource needs, Robustness/Reliability, Implementation delay, Applicable to safety critical tasks, Availability, Evaluation and Independence on humans during operation.

- Efficiency – How well the barrier meets its intended purpose;
- Cost – What is needed to design, develop and maintain a barrier;
- Reliability – The ability to maintain its functions in routine circumstances;
- Implementation delay – The time from conception to implementation of a barrier;
- Applicable to safety critical tasks – The use in safety tasks;
- Availability – Whether a barrier can fulfill its purpose when needed;
- Evaluation – How easy is to determine whether a barrier works as expected;
- Independence on humans – The ability of not depending on humans to achieve its purpose.

Table 2.3 shows the above quality attributes of each barrier system.

**Table 2.3 - Evaluation of barrier system quality (Adapted from Hollnagel, 2008, p. 228)**

| Quality | Physical | Functional | Symbolic | Incorporeal |
|---|---|---|---|---|
| **Efficiency** | High | High | Medium | Low |
| **Cost** | Medium-High | Low-Medium | Low- Medium | Low |
| **Reliability** | Medium-High | Medium-High | Low- Medium | Low |
| **Implementation delay** | Long | Medium-Long | Medium | Short |
| **Applicable to safety critical tasks** | Low | Medium | Low | Low |
| **Availability** | High | Low-High | High | Uncertain |
| **Evaluation** | Easy | Difficult | Difficult | Difficult |
| **Independence on humans** | High | High | Low | Low |

*"A* ***Barrier Function*** *is a function planned to prevent, control, or mitigate undesired events or accidents." (Sklet, 2006b, p.496).*

The function of the barrier describes the safety barriers objective, what they must do to prevent, control or mitigate. The function must be defined by a noun and a verb, as example, "open door" or "initiate machine". A barrier function may have several barrier systems to fulfill its purpose, as for example: to prevent a fall from rooftops, it can be made of iron grids. If the function is well implemented and, when required in case of an accident or undesired event, successfully performed, it should reduce its consequences. There are some examples of barrier functions shown before in Table 2.2.

Hollnagel states that the term barrier is a synonym of barrier function, and it should be used that term instead of just barrier, as a short-hand reference to a barrier function implemented by a barrier system. (Hollnagel, 2008, p. 227)

"***Safety barriers*** *are physical and/or non-physical means planned to prevent, control, or mitigate undesired events or accidents." (Sklet, 2006b, p.496).*

These items can be simple technical units or human actions. To prevent means to reduce the probability of danger; to control is to make a limit to the extension and/or duration of danger; to mitigate is to reduce the undesired effect of several dangers, such as technical failures, human errors, external events or the simple combination of those. This implies that at least one of the purposes of a safety barrier is to reduce the risk, and it should be directly related to the accident scenario. Safety barrier diagrams can be used to represent a comprehensive documentation of event sequences (Fig. 2.4).

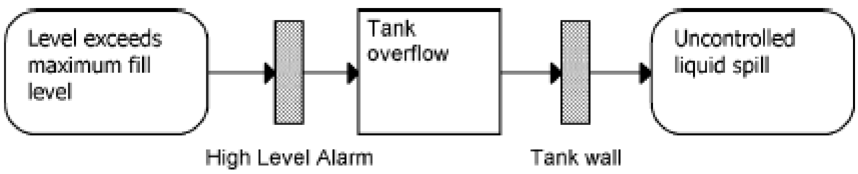


**Figure 2.4 - Example of safety barrier diagram (Dujim, 2009, p. 333)**

### Safety Function (SF)

The term used to describe a safety function may change, as it is a rather common term. The one adopted in this work focus, mainly, on the concept of Safety Function (SF), defined in literature by Harms-Ringdahl (2009, p. 353) such as:

"*A safety function is a technical or organizational function, a human action or a combined of these, that can reduce the probability and/or consequences of accidents and other unwanted events in a system.*"

The term Safety Function is a large concept and requires more factual characterization in different and specific applications. Technical and organizational safety features, as well as social factors and individual behavior, contribute in an essential way to the safety level at the workplace. In practical and operational applications, any Safety Function can be described by a set of parameters. Harms-Ringdahl (2009, p. 354) proposes four main parameters: Level of abstraction, System level, Type of safety function and type of object.

The *Level of abstraction* is situated in the lower level of the specific solution, e.g. a safety relay or a temperature guard. At higher levels it can refer to protection against excessive temperatures.

The *System level* is related to the hierarchy where the system is included. An example of a hierarchy division is referred by Harms-Ringdahl (2003a, b) as *component, subsystem, machine, department and factory*.

The *Type of safety function* indicates if the function is technical, organizational or human intervention, yet functions where safety is not the main objective could have some essential safety features.

The *Type of object* characterizes the system to be protected; it might be a technical system, control room, etc.

A safety function can be described by a set of attributes that characterize their contribution on safety conditions:

- Intention - indicates, in a certain way, the quality and influence of the safety function and it's divided into four categories;
- Importance - refers to the influence of the Safety Function in the safety system; it can be split into four categories as well;
- Efficiency - indicates how the Safety Function achieves its purpose in a better or worse way. It is defined as the "probability" that a safety device performs its intended function when is needed to. Sometimes "probability of success" is a better term.

### 2.1.3 Methods (Tools)

In this section the author of this thesis will make a brief summary of the methods used in the area of safety analysis and risk assessment. Anyone who wants to assess a certain risk and make a safety analysis must chose and use at least one method from a large range of available methods.

There are two main kinds of approaches in these methods (Table 2.4); the ones that are technically oriented and the systems oriented. The first ones aim to a systematic approach of risk and presuppose a good knowledge of the system and technology in study; the systems oriented consider the links between technical aspects, people and organization.

**Table 2.4 - Some methods of Safety Analysis (adapted from Harms-Ringdahl, 2001, p. 41)**

| | **Method** |
|---|---|
| **Technically oriented** | Energy Analysis |
| | HAZOP (*Hazard and Operability Studies*) |
| | FTA (*Fault Tree Analysis*) |
| **Systems Oriented** | JSA (*Job Safety Analysis*) |
| | Deviation Analysis |
| | Task Analysis |
| | SFA (*Safety Function Analysis*) |

It should be noted that currently there are a large number of methods available (e.g.: review of literature by Aven, 2009). However, this is a short review and only the most relevant will be summarized, especially those that are more frequently described and/or applied in the context of occupational risks on a day-to-day basis by many enterprises; i.e., this is not only a summary, but also a more "practice-oriented" review. According to Harms-Ringdahl (2001), for instance, the **Energy Analysis** method was first developed by Gibson in 1961 and Haddon around 1963 and then, after being proved useful, some authors like Johnson (1980) and Haddon himself in 1980 made some further developments. The purpose of this method is to obtain an overview of all the possible energies capable of harming someone in an installation, being energies (e.g. kinetic, potential, electrical, thermal, chemical, biological, etc.) known as something present in the installation that can, physically, biologically or chemically, harm a person when connected to a specific event.

The energy analysis is performed in four main steps:

1. Dividing the system into a number of parts, to be analyzed individually;
2. Identifying energies for each divided part, with the help of a structured checklist of energies;
3. Assessing the identified energy sources. This can be done in different ways, using different methods (i.e., complementary approaches);
4. Making proposals for improvements.

Its main advantages are an easy form of application and the systematic identification of energy barriers aiming prevention and protection.

According to Kletz (2001), the **HAZOP** was developed by ICI *Petrochemicals Division* in 1963, but it was first published only in 1974 by Herbert G. Lawley (cited by Harms-Ringdahl, 2001). Its main concept is a systematic and extensive search, using keywords in guidance, of deviations that can cause serious harm. It provides the opportunity for people to think of every possible ways in which hazards might arise, reducing the chance that something is missed. The characteristic elements of an HAZOP analysis are:

- Intention – For each part of the installation, previously divided, is defined a specific intention.
- Deviation – All the possible deviations from the normal functioning that can cause dangerous events.
- Key-Word – Used to guide the search to identify the different types of deviations.
- Team – The analysis is always executed by a team composed with specialists from different areas.

The **FTA** (***Fault Tree Analysis***) is a logical method based on tree diagrams, representing logical relations of the possible causes that lead to the system failure or accident. This method was firstly used in the 1960s; there is extensive literature on it by Kumamoto and Henley (1996); however it is difficult to be applied so, generally, only specialists use it. Its advantages are: the ability to aid identifying risks in complex systems; provides an overview on how faults can lead to consequences and it is restricted to the identification of the system and component causes that lead to one particular top event. On the other hand, one important disadvantage is the requirement of expertise knowledge and training to execute it, once mistakes are difficult to find and the logic is difficult to follow.

When turning to the “systems oriented” methods, the **JSA (*Job Safety Analysis*)**, focuses on human tasks. It analyses the tasks performed by a person or group of persons, and it is best fitted to use in well defined tasks and its sequences (e.g. automobile manufacturing lines, air controllers, etc.). The method was firstly approached and described by Grimaldi in 1947 (cited by Harms-Ringdahl, 2001).

**Deviation Analysis** was introduced by Urban Kjelén in 1970s in job analysis, and later in the 1980s, Harms-Ringdahl adapted it for risk assessment and analysis of production systems (Harms-Ringdahl, 2001). The aim of this method is to identify deviations that can cause an accident; the main idea of this is that deviations can represent an hazard. However, sometimes it happens to gather positive deviations, which increase safety conditions. It is important to identify these exceptions because they should be used later as a standard procedure (or a safer method of work).

**Task Analysis** is a methodology that can offer valuable support in assessing and controlling risks; it covers a range of human factors techniques aiming at what manual workers and process operators do. There are “action oriented” approaches and cognitive approaches (Harms-Ringdahl, 2001).

The **SFA (*Safety Function Analysis*)** method is based in the concept of safety functions, and it was developed by Harms-Ringdahl (Harms-Ringdahl, 2001, 2003a). The method is generic and it can be applied to several systems, having the general objective to identify and analyze safety functions involved in a specific event. However the evaluation of how well the safety functions work and suggestions for improvements or entering new safety functions, are also important aims within the spirit of SFA

This method has two different areas of application: it can be used in an accident investigation, in this case only a set of all the possible safety functions in the system will be assessed; or it can focus directly on the system, identifying all of its safety functions, using a pro-active approach towards the improvement of safety.

The analysis procedure has a set of stages, including a preparation phase and a concluding phase to report the results. However, there are six specific main stages:

1. Hazard Selection;
2. Identification of safety functions;
3. Structuring and classification of these functions;
4. Estimate the efficiency of the safety functions;
5. Assessing whether improvements are necessary;
6. Proposing improvements.

Since this method is the one used in the present study, it will be explained in more detail in the third chapter (Methodology).

## 2.2 *EU Directives and practical/legal requirements*

This section of the dissertation marks the transition to more practical issues, namely the legal framework that is given by "*Decreto-Lei n.º50/2005*" referring to equipments, and "*Decreto-Lei n.º103/2008*" referring to machinery. The legal requirements of each document above mentioned were converted into a check-list that was used as an aid during the analysis carried out within this work. The most relevant requirements of each law are summarized next.

**Use of Equipment**

The Decree DL 50/2005 from 25$^{th}$ February transposes into the Portuguese law the directive number 89/655/CEE, modified by directive number 95/63/CE and by directive number 2001/45/CE from the European council, related to the minimal prescriptions of safety and health for the use of equipment by workers. This is applied in all kind of industries.

In Chapter I of decree DL 50/2005 it is referred that to assure the safety and health of workers when using the equipments, the employers must assure that the equipments are appropriate or conveniently adapted to the work in progress and that it guarantees safety during its utilization (Art. 3.a). When choosing equipment, they also must attend to work condition and specific characteristics, to the actual risks and possible ones resulting of equipment utilization (Art. 3.b). The proper maintenance of equipment during its utilization period must also be assured, so that they respect the minimum safety requirements and don't cause any hazard to workers safety and health (Art 3.e). This chapter also refers that the employers must proceed to periodic verifications and if necessary, essays of work equipment that is exposed to some influences causing deterioration and consequently possibility of risk. They must proceed also to extraordinary verifications of work equipment, when facing exceptional events or long periods of none utilization, that may have severe consequences for safety. These verifications and equipment essays above referred must always be executed by a qualified person, to ensure proper installation and good functioning (Art. 6).

Regarding work equipment involving specific risks, the employer must take special precautions so that the use of that equipment is only made by an operator qualified for the corresponding activity (Art. 5).

The employer must also give proper and easy understanding information, to workers and to the safety and health representatives, about the equipment used. That information must have indications of conditions for use of equipment, abnormal predictable situations, acquired experience from the use of equipment and possible due risks (Art. 8).

The second chapter, section II (DL 50/2005), establishes the minimum safety requirements for work equipment, applied to the extent that the corresponding risk exists in the work equipment in question. These minimum requirements are divided in articles, shortly described below.

Control Systems – must be plainly visible, identifiable and, if appropriate, have a proper markup. They also must be safe and choose regarding fails, predictable disturbances and limitations in the use for which they were designed (Art. 11).

Equipment Startup – A voluntary action must be applied over a control to start the equipments after a stop of any kind, unless the stop results of a normal sequence or an automatic work cycle (Art. 12).

Equipment Stop – It must be provided with a control system that allows it to stop in safety conditions, as well as an emergency stop device if necessary. The stop should have priority over the start controls. The energy supply to the actuators of the work equipment should be stopped whenever there is a stop of itself or its dangerous elements (Art. 13).

Stability and Rupture or disintegration of parts – The equipment as its respective elements must be stabilized by means of fixation or any other means whenever the safety of workers justifies it (Art. 14).

Projections and Fumes – The work equipments must have efficient retention or extraction devices located near the focus point (Art. 15).

Risk of Mechanical contact – The moving elements liable of causing accidents by mechanical contact must have protecting devices with robustness that stop the access to dangerous areas, or devices that interpose the movement of elements before they access those areas. They must be situated in a secure distance and must not limit the work cycle observation (Art. 16).

Illumination and Temperature – The equipment must be conveniently illuminated regarding the work to process. They also must be protected against the risk of contact or proximity with high or low temperature parts (Art. 17).

Warning Devices – They must be clearly heard and easily understood without ambiguity (Art. 18).

Equipment Maintenance – The maintenance operations must be done with the equipment stopped, when not possible, the necessary caution measures must be assured to execute such tasks. The maintenance manual must be updated (Art. 19).

Electric, fire and explosion risks – The equipment must protect the workers from direct or indirect contact with electricity, fire, overheat, gas release or explosion (Art. 20).

Energy sources – The equipment must have devices that allow isolating themselves from their external energy sources, and in case of reconnection, this must be done with no harm for the workers (Art. 21).

Safety Signs – The equipment must be clearly signaled with warnings or other indispensable signals to guarantee the workers safety (Art. 22).

In section III (DL 50/2005), the additional requirements of mobile equipments are described, in which such as the equipments that transport workers and the risk of rolling over, energy transmission, and forklift rollover risk. Finally, section IV (DL 50/2005) describes the additional requirements for lifting loads. Those equipments for such purpose, permanently installed, must maintain its robustness and stability during an action of lifting, taking into account what kind of loads are being lifted and the corresponding forces exercised in the suspension or fixation points. They must also be installed in such way to reduce the risk of collision with the workers, or the risk of balancing, tilt and fall unwittingly (Art. 27). Also, the lifting loads equipment must clearly indicate their nominal load and, if necessary, the nominal load for each machine configuration. The elevation accessories must have a sign that can identify their safety use, and if the equipment is not meant for workers elevation, it must have the proper prohibition sign within it (Art. 28). The rules for use of work equipment are also established in Chapter III.

**Machinery**

The Decree DL 103/2008 from 24$^{th}$ June, which regulates the placing on the market of machines, transposes to internal law the European Directive n.º 2006/42/CE; this decree clarifies a number of safety requirements concerning machines and machine components. It also introduces the concept of partly completed machinery and establishes rules for its allocation in the market.

The legal requirements apply to the following products:

- Machinery;
- Interchangeable equipment;
- Safety components;
- Lifting accessories;
- Chains, ropes and webbing;
- Removable mechanical transmission devices;
- Partly completed machinery.

For the purposes of this Directive, "machinery" designates the products listed in Article 1, (a) to (f). The following definitions shall apply:

(a) "*Machinery*" means:

- an assembly, fitted with or intended to be fitted with a drive system other than directly applied human or animal effort, consisting of linked parts or components, at least one of which moves, and which are joined together for a specific application,

- an assembly referred to in the first indent, missing only the components to connect it on site or to sources of energy and motion,

- an assembly referred to in the first and second indents, ready to be installed and able to function as it stands only if mounted on a means of transport, or installed in a building or a structure,

- assemblies of machinery referred to in the first, second and third indents or partly completed machinery referred to in point (g) which, in order to achieve the same end, are arranged and controlled so that they function as an integral whole,

- an assembly of linked parts or components, at least one of which moves and which are joined together, intended for lifting loads and whose only power source is directly applied human effort;

(b) "*interchangeable equipment*" means a device which, after the putting into service of machinery or of a tractor, is assembled with that machinery or tractor by the operator himself in order to change its function or attribute a new function, in so far as this equipment is not a tool;

(c) "*Safety component*" means a component:

- which serves to fulfill a safety function;

- which is independently placed on the market;

- the failure and/or malfunction of which endangers the safety of persons;

- which is not necessary in order for the machinery to function, or for which normal components may be substituted in order for the machinery to function.

(d) "*lifting accessory*" means a component or equipment not attached to the lifting machinery, allowing the load to be held, which is placed between the machinery and the load or on the load itself, or which is intended to constitute an integral part of the load and which is independently placed on the market; slings and their components are also regarded as lifting accessories;

(e) "*chains, ropes and webbing*" means chains, ropes and webbing designed and constructed for lifting purposes as part of lifting machinery or lifting accessories;

(f) "*Removable mechanical transmission device*" means a removable component for transmitting power between self-propelled machinery or a tractor and another machine by joining them at the first fixed bearing. When it is placed on the market with the guard it shall be regarded as one product;

(g) "*Partly completed machinery*" means an assembly which is almost machinery but which cannot in itself perform a specific application. A drive system is partly completed machinery. Partly completed machinery is only intended to be incorporated into or assembled with other machinery or other partly completed machinery or equipment, thereby forming machinery to which this Directive applies.

Article 5, Freedom of movement refers that before imputing a machine to the market, the Member States shall not prohibit, restrict or impede the placing on the market and/or putting into service in their territory of machinery which complies with this Directive. Member States shall not prohibit, restrict or impede the placing on the market of partly completed machinery where the manufacturer or his authorized representative makes a declaration of incorporation, stating that it is to be incorporated into machinery or assembled with other partly completed machinery to form machinery. Still, at trade fairs, exhibitions, demonstrations, and such like, Member States shall not prevent the showing of machinery or partly completed machinery which does not conform to this Directive, provided that a visible sign clearly indicates that it does not conform and that it will not be made available until it has been brought into conformity. Furthermore, during demonstrations of such non-conforming machinery or partly completed machinery, adequate safety measures shall be taken to ensure the protection of persons.

## 2.3 Synthesis of chapter

Within the area of dependability and reliability, risk is an hazard measure of an unwanted event and the combined consequences that come with it. So when assessing risk, one must estimate its magnitude and decide about its acceptability.

Safety analysis is, on the other hand, a procedure to analyze systems, identify, and evaluate hazards and safety characteristics. One of the main concepts analyzed in this Chapter were barriers, which are reactive and proactive forms, however safety can't be assured only by reacting, it must look to the future being proactive, yet it can happen that the required investment to prevent unwanted events can be a risk if nothing takes place in time.

It was also discussed, in a briefly way, the methods used to analyze safety and assess risk, however, depending on what kind of approach the analyst wants to make, he can chose from two main different kinds, or three if we consider the hybrid approach.

# 3. Methodology

## 3.1 *Introduction*

The general methodology of this work is based in a case study approach with a timeline of about five months. The choice of the processes studied was based on the number and type of hazards identified previously by Renova: not only do they have more safety functions to assess, but also are the most hazardous.

The current study has applied the new modified version of Safety Function Analysis; the original version of SFA appeared in 2001 (Harms-Ringdahl, 2001; Harms-Ringdahl, 2003a), but Harms-Ringdahl has developed it further in May 2011 (Harms-Ringdahl, 2011). This new version will be commented and described below, explaining what changes in comparison with the previous version and why those changes were made.

The author of this thesis spent a full-time week in a company of paper transformation called Renova, where he has made direct observation of the production processes. Furthermore, informal discussions with operators and line managers were also performed.

At first, this chapter will describe the risk assessment procedure currently used in the company for general application. Then the original version of the SFA method (Harms-Ringdahl, 2003) is explained. The chapter ends with the description of the modified version of SFA, where a flowchart is presented for a better understanding, with the main differences between the two versions of the method.

The study itself continues with the application of the above mentioned SFA approach, the discussion of the main results and the relevant conclusions, which are included within the subsequent chapters.

## 3.2 *Risk Assessment – method currently used in Renova*

The method used by Renova in risk assessment is a modified version of the well-known William T. Fine (Fine, 1971). This method starts with the evaluation of the working station, being necessary to compile all the important information, like legislation, machinery instructions' manual, safety sheets of dangerous substances, work methodologies, etc, aiming to detect the *level of deficiency* (LD) in the workplace. Its classification must take into account several risk factors, which may have a direct causal relationship with the possible accident. Table 3.1 shows a way to classify the level of deficiency.

**Table 3.1 - Level of Deficiency classification (Renova, 2011; WTF modified)**

| Level of Deficiency (LD) | Scale | Definition; Descriptions |
|---|---|---|
| **Acceptable** | 1 | Deficient factors were not detected.<br>Risks are controlled. |
| **Insufficient** | 2 | Minor important deficient factors were detected<br>Existent preventive measures can be improved |
| **Deficient** | 6 | Significant deficient factors were detected<br>Some preventive existing measures are not quite efficient |
| **Very Deficient** | 10 | The preventive existing measures are not efficient<br>Hazard will be present in most circumstances |
| **Totally Deficient** | 14 | There are no preventive measures<br>There are no safety rules for the activity observed<br>Hazards associated with the activity are unknown |

Another important factor is the *level of exposure* (LE), this factor indicates the frequency of exposure of a worker to hazards, estimated through the time of permanence in the workplace or machinery operations, etc. Table 3.2 shows the given scores to the level of exposure.

**Table 3.2 - Level of exposure classification (Renova, 2011; WTF modified)**

| Level of Exposure (LE) | Scale | Definition |
|---|---|---|
| **Sporadic** | 1 | Once a year, maximum. |
| **Low frequency** | 2 | More than once a year. |
| **Occasional** | 3 | More than once a month. |
| **Frequent** | 4 | Several times during the work period, several times a week or daily. |
| **Continuous** | 5 | Several times per day, continually. |

The *level of probability* (LP) can be scored by the product of the *level of deficiency* (LD) and the *level of exposure* (LE). Table 3.3 shows the scale of this level.

**Table 3.3 - Level of Probability (Renova, 2011; WTF modified)**

**(LP = LE x LD)**

| Level of Probability (LP) | Scale (Scoring) | Definition |
|---|---|---|
| **Very Low** | [1 – 3] | The hazard situation is not expected to occur in the installation lifetime. |
| **Low** | [4 – 6] | The hazard situation may occur in the installation lifetime. |
| **Medium** | [8 – 20] | The hazard situation may occur in medium-term |
| **High** | [24 – 30] | The hazard situation may occur in short-term. |
| **Very High** | [40 – 70] | The hazard situation is almost certain to occur. |

By definition, as also shown in Chapter 2, "risk" is the combination of the probability of occurrence of an event and its injuries gravity (consequence). From the definition arises the term *level of consequence* (LC) which may be scaled as shown in table 3.4. The *level of risk* (LR) is the result of the product between the *level of probability* and the *level of consequence*. Table 3.5 shows the kind of control that must be followed according to the scored *level of risk.*

**Table 3.4 - Level of Consequence (Renova, 2011; WTF modified)**

| Level of consequence (LC) | Scale | Definition |
|---|---|---|
| **Insignificant** | 10 | Without human injuries or illnesses. |
| **Low severity** | 25 | Minor injuries without losing the work capability. |
| **Moderated** | 60 | Irreversible injuries with temporary incapacity. |
| **Severe** | 90 | Severe and irreversible injuries with permanent incapacity or even death. |
| **High Severity** | 155 | One or more death. Full incapacity. |

The criteria used to define the *acceptability* will depend on the priorities of each company; Renova considered that a level of risk higher than 360 is always non acceptable, which implies that measures must be take to eliminate or reduce the hazard to the minimum as possible.

**Table 3.5 - Level of Risk evaluation (Renova, 2011; WTF modified)**

**(LR = LP x LC)**

| Level of Risk (LR) | Control level | Situation | Measures |
|---|---|---|---|
| **[3000 – 10850]** | I | Critical | Immediate intervention;<br>Possible activity stop;<br>Isolate the hazard until measures are adopted. |
| **[1250 – 3000]** | II | To be corrected | Adopt alternative control measures, while the situation is not reduced or eliminated;<br>Plan improvements within short-term. |
| **[360 – 1250]** | III | To improve | Plan alternative forms of work execution;<br>Possible improvements of the existent conditions;<br>Create procedures of safety instructions for the activity. |
| **[100 – 360]** | IV | Controlled | Act only if exists capacity and improvement opportunity. |
| **[10 – 100]** | V | No intervention necessary | Activity monitoring. |

## 3.3 *Safety Function Analysis (2001, 2003a)*

The method SFA – Safety Function Analysis, is based on the concept of safety functions, and it was developed by Harms-Ringdahl in 2001. As already mentioned, the method is generic and it can be applied to several systems, having the general objective to identify and analyze safety functions involved in a specific event. However the evaluation of how well the safety functions work and suggestions for improvements or entering new safety functions, are also important aims to get in the SFA.

This method has two different areas of application: it can be used in an accident investigation, in this case only a set of all the possible safety functions in the system will be identified; and it can focus directly on the system, identifying all of its safety functions.

The analysis procedure has a set of stages, including a preparation phase and a concluding phase to report the results. However, there are six specific main stages, represented below (Figure 3.1).

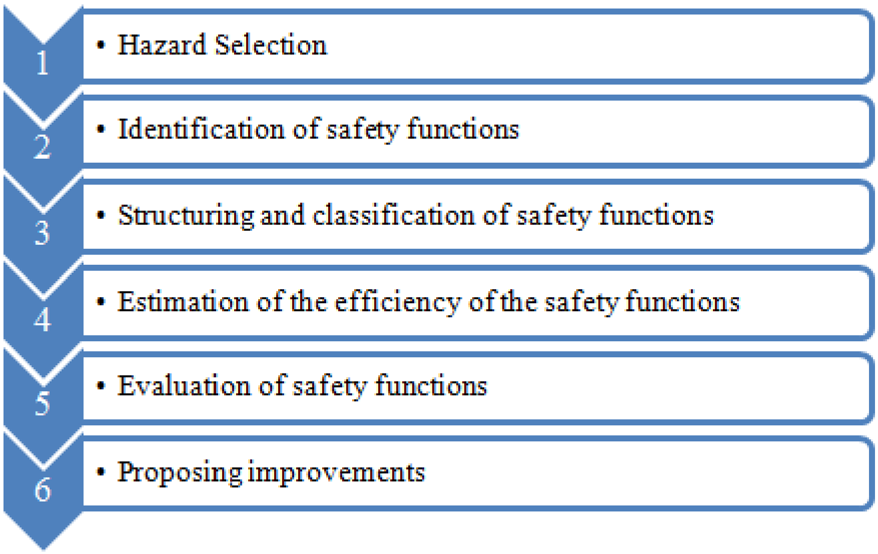


**Figure 3.1 - The six stages of SFA (adapted from Harms-Ringdahl, 2003a)**

### Step 1 - Hazard Selection

The **hazard selection** can be done using any traditional method of risk analysis, as the ones described earlier in Chapter 2.1.3. From these methods **the most significant hazards** are chosen to be analyzed. The methodology used by Renova to identify the hazards and assess the risk level is W.T. FINE (modified). This approach was just described in the previous section.

### Step 2 - Identification of Safety Functions

For the second stage, there are several ways to **identify the safety functions**; it can be done using a structured "checklist" with a set of safety functions (EU-Agency, 2007), or identifying the ones that are relevant to the hazard analyzed. Other method is the use of documents reporting accidents where the analyst tries to identify statements or just simply words that can indicate a safety function; similar to a text analysis, this can be done through interviews and discussions with a group of people, where the analyst can pick sentences or words that can be understood as safety functions when posing questions to the group about what started the accident or what could have been done to prevent it. Such questions should be of the following kind:

- How to keep low the probability of the accident?
- How to keep low the consequences of the accident?
- How to reduce the accident seriousness if it happens?

In this work, the identification of safety functions was made with the help of an existent checklist created by Renova engineers, together with an extensive observation of the process performed by the author of this work and taking into account the present machinery and use of equipment legal requirements.

**Step 3 - Structuring and classification of Safety Functions**

In the third stage, the safety functions identified and generated in an arbitrary order are **structured** into a logical way to facilitate their assessment. When structuring the SFs it might be useful to use the parameters described in Chapter 2.1.2 for defining a safety function:

- Level of abstraction;
- System level;
- Type of safety function;
- Intention of safety function.

The *Level of abstraction* is situated in the lower level of the concrete solution, e.g. a safety relay or a temperature guard. At higher levels it can refer to protection against excessive temperatures.

The *System level* is related with the hierarchy where the system is included. An example of a hierarchy division is referred by Harms-Ringdahl (2008) as *component, subsystem, machine, department and factory*.

The *Type of safety function* indicates if the function is technical, organizational or human intervention, yet functions where safety is not the main objective could have some essential safety features.

The *Intention of safety function* characterizes the system to be protected; it might be a technical system, control room, etc.

However the safety functions can also be divided by selecting a few categories, depending on the results from the identification stage. They can be structured by type of safety function, such as technical, organizational or human, by organizational aspects (how the safety function is related to organizations to which they belong) or by accident sequence.

Based in the criteria used, each safety function is classified and ready to be sorted according to the classification made. After the sorting, the safety functions are in a better order, allowing the analyst to find identical or even repeated safety functions and correct them. The structuring step should be seen as an iterative process which creates an improved structure.

### Step 4 – Estimation of the efficiency of the Safety Functions

To **estimate the efficiency of a safety function**, in the fourth stage, one needs to evaluate it using a certain number of characteristics. According to Harms-Ringdahl (2001, 2003a), the characteristics shown in Table 3.6, and its categories, can be applied.

**Table 3.6 - Categories of SF characteristics (Harms-Ringdahl, 2003a, p. 707)**

| Characteristics (a) | Categories | |
|---|---|---|
| **Intention** | 0 | No intended SF, and no influence on safety |
| | 1 | No intended SF, but some influence on safety |
| | 2 | Intended SF, but main purpose is something else |
| | 3 | Intended to provide safety, or reduction of consequences |
| **Importance** | 1 | No influence on safety |
| | 2 | Small influence |
| | 3 | Rather large influence |
| | 4 | Large influence, closely connected to accident or size of consequences |
| **Efficiency** | Defined as being the probability of an item exist and perform its function when required. | |

(a) – These are the characteristics proposed within the original SFA method.

The **Intention** of a safety function has its most importance at the design stage, when it is essential to define intentions according to different solutions. This can be divided into four categories shown in the table above.

**Importance** should assume that a safety function works as it should, reflecting its bigger or lower influence on safety. It is also divided and evaluated in four categories (Table 3.6).

**Efficiency** can be seen as a combination of reliability and the probability of the safety function to take place in time. The success rate is directly related to how the safety function works, the bigger the success rate is, the best work is performed by the SF. This rate ranges from 0% to 99,99%.

**Step 5 – Evaluation of the safety functions**

The next step is to **assess the safety functions** in a systematic and consistent way following a pre-defined scheme, judging either the function is acceptable offering enough safety to control the hazard, or if improvement is necessary. Harms-Ringdahl (2001, 2003a) uses a scale, represented on Table 3.7, to apply the judgment and establish any improvement measures if necessary. This decision about acceptability is made for each safety function taking into account the characteristics previously mentioned (Intention, Importance and Efficiency).

**Table 3.7 - Scale to apply judgment of acceptability (Harms-Ringdahl, 2001, 2003a)**

| Code | Description |
|---|---|
| **0** | Acceptable, negligible risk |
| **1** | Acceptable, no changes required |
| **2** | Not acceptable, system change (safety measure) is recommended |
| **3** | Not acceptable, system (safety measure) is necessary |

**Step 6 - Proposing improvements**

After deciding whether a safety function is acceptable or not, it might be necessary to **propose improvements**, aiming to increase efficiency and/or to eliminate weak points. These improvements must be specific for each SF, and they must be ordered by priority, according to the analyst decision.

In this original version, however, there is no guidance on how to judge the several possible combinations of the criteria used, i.e., no instrument to achieve the final decision in an objective way. This limitation was probably not felt when using the method on the basis of a single case study, especially for research purposes. However, the lack of a final guidance reduces "repeatability" when the method is applied on a more routine basis by field professionals.

## 3.4 *Safety Function Analysis (New development; Harms-Ringdahl, 2011 draft)*

The flowchart depicted in figure 3.3 illustrates, in a simplified way, the main differences between the original SFA version of 2001 and the modified version proposed by Harms-Ringdahl in 2011. As it can be seen, the three first stages are the same for the two versions; the main differences only manifest in the next steps.

While the previous version of SFA splits the estimation of efficiency and evaluation in two different steps, the fourth step of the 2011 version aggregates them, and it is renamed as "Evaluation of Safety Functions". This stage turns out to be of great importance in the whole procedure, since this is where the safety functions are characterized and evaluated for necessary changes in the safety level.

So, in this new stage (Step4) the characteristic **Intention** is merely informative; it is not an essential or necessary parameter, but it can give important information on how the safety function works (*c.f.* Table 3.8).

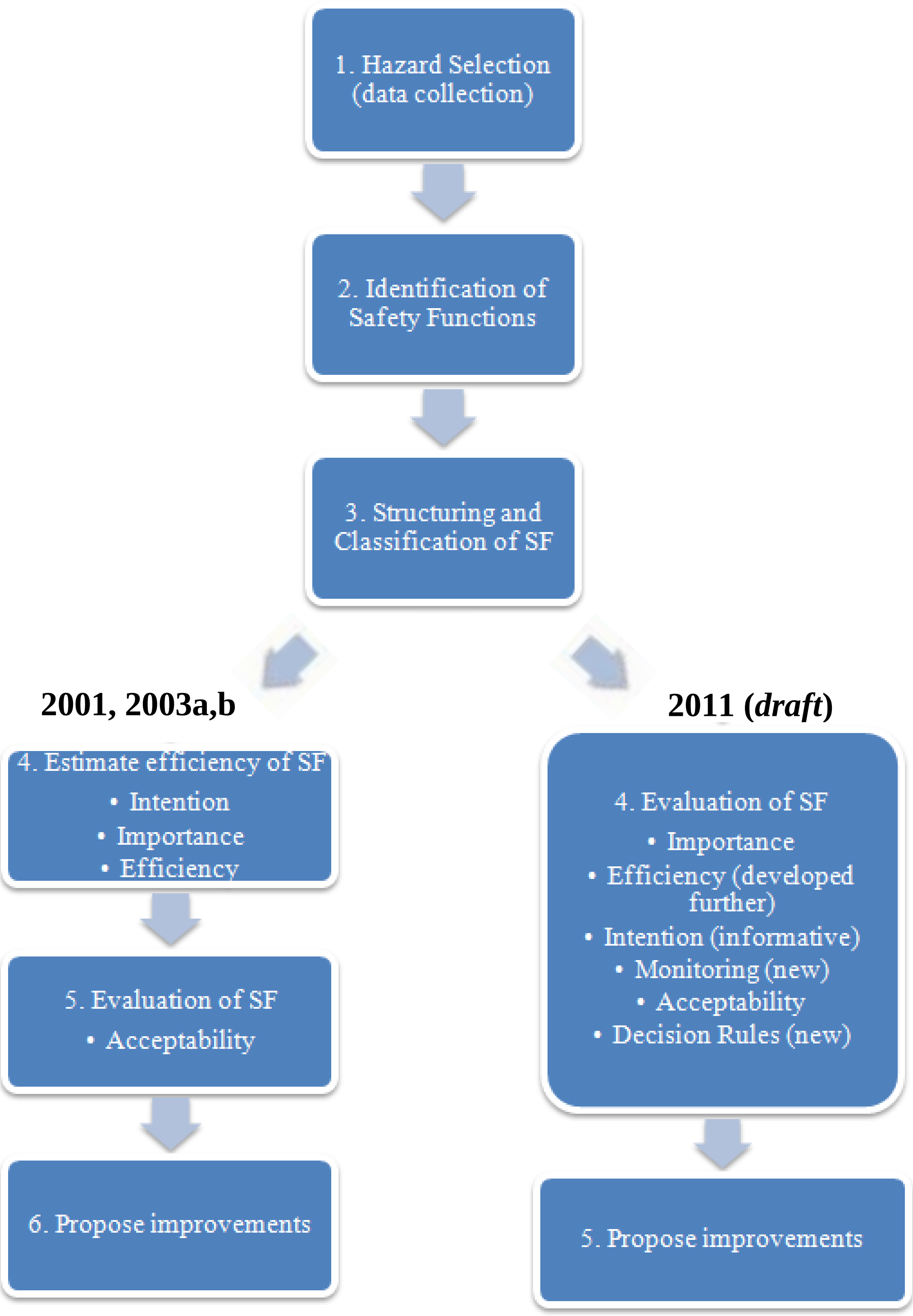


**Figure 3.3 - Flowchart representing differences between SFA versions of 2001 and 2011**

**Table 3.8 - Classification of Intention of Safety Functions (Harms-Ringdahl, 2011 draft, chapter 11)**

| Code | Description |
|---|---|
| **0** | No intended safety function and no influence on safety. |
| **1** | No intended safety function, but influence on safety |
| **2** | Intended safety function, but main purpose is something else |
| **3** | Intended to provide a safety function |
| **4** | Intended to provide a safety function through a formal system |
| **9** | Uncertain intention |

**Importance** maintains its four types of categorization; however the codes and descriptions had slightly changed (Table 3.9).

**Table 3.9 - Classification of Importance of SF (Harms-Ringdahl, 2011 draft, chapter 11)**

| Code | Description |
|---|---|
| **0** | SF has no or very small influence on safety |
| **1** | Small influence on safety |
| **2** | Rather large influence on safety |
| **3** | Large influence on safety |

As for **Efficiency**, this characteristic is better defined using now new parameters to identify efficiency, such as “probability to function” and “Error frequency”; the last one looks over specific time periods to scale the type of efficiency. For example, a function that has probability of 0%, always fails, and if the probability is between 50% and 89% or, alternatively, it can be said that the error frequency is less than 100 times a year, the function has a low efficiency. The full range is tabled below. There are two kinds of efficiency (*Estimated* and *Wanted*), the *Wanted Efficiency* refers to the best classification the company wishes to have in that process, so that one can give a score to the *Estimated Efficiency* by comparison.

**Table 3.10 - Scale of efficiency for SF based on frequency of error or probability (Harms-Ringdahl, 2011 draft, chapter 11)**

| Code | Efficiency | Probability to function | Error Frequency |
|---|---|---|---|
| **0** | Very Low | < 50% | - |
| **1** | Low | > 50% | < 100 times / year |
| **2** | Medium | > 90% | < 10 times / year |
| **3** | High | > 99% | < 1 time / year |
| **4** | Very High | ≥ 99,99% | < 0,01 time / year |

**Monitoring** is a new characteristic included in the analysis, which evaluates the need for monitoring the safety functions and also their present performance. The efficiency of a safety function can get lower with time passing by, so this is a very important system that helps to maintain the function's performance. There are different levels of monitoring, according to the status of performance. Table 3.11 shows the different status and the corresponding need (or no need) for monitoring. The monitor *status* is the most important attribute for the evaluation of the criterion "monitoring".

**Table 3.11 - Need of monitoring, and judgment of status (adapted from Harms-Ringdahl, 2011 draft, chapter 11)**

| Code | Needs (requirements) | Status | Code |
|---|---|---|---|
| **MN4** | Monitoring is essential | Meets the requirements | **MS2** |
| **MN3** | Monitoring is necessary, at least periodically | Exists, but not fully meet the requirement | **MS1** |
| **MN2** | Monitoring is of interest, but not a critical issue | Monitoring function does not meet requirement | **MS0** |
| **MN1** | Of low interest | Ok, no need for monitoring | **MS2** |
| **MN0** | Not needed or irrelevant | Ok, no need for monitoring | **MS2** |

Table 3.11 shows that, for instance, a critical SF in which monitoring is "essential" (MN4) can be classified within different status (MS2, MS1, or MS0) depending on how well (or not) the SF is being monitored in practice. The same reasoning applies for categories MN3 and MN2.

The **Acceptability**, is now better defined and more accurately; this is likely to reduce subjectivity and, therefore, to increase validity or robustness of the results. In this version it corresponds to a first simple evaluation, aiming to decide whether improvements are necessary in a safety function to reduce or control the hazard (Table 3.12). However, an "advanced evaluation" can be made for certain systems with potential for large consequences, aiming to support engineers with knowledge about the system. This "advanced" analysis was not carried out in the present work.

**Table 3.12 - Evaluation scale for acceptability of safety function (adapted from Harms-Ringdahl, 2011 draft, chapter 11)**

| Acceptability | Code | Description |
|---|---|---|
| **Acceptable** | 0 | No need for improvement. |
| | 1 | Improving safety function can be considered. |
| **Not Acceptable** | 2 | Improving safety function is recommended. |
| | 3 | Improving safety function is essential. |
| | 4 | Intolerable, work should not be started or continued until the risk has been reduced. |

Directly linked with acceptability arises the last and new characteristic added to this new version, the **Decision Rules** (Table 3.13), which is an algorithm that considers various possible combinations of criteria to decide the level of acceptability.

Logical expressions can be created by having these decision rules established, for possible further use in database programs (Harms-Ringdahl, 2011 draft, chapter 11).

This table (3.13) works as a *decision tree* to help reducing subjectivity of analysts; this new instrument can be particularly useful in the case of less experienced safety professionals. Common industry practitioners felt the need for some kind of "guidance" or "rule of thumb" on how to assess the possible combinations of the several criteria, i.e., to have a means to "link the ties" at the end in a more standardized way. This motivated the revision of the SFA method in 2011.

**Table 3.13 - Table of decision rules for SFs (Harms-Ringdahl, 2011 draft, chapter 11)**

| Importance IMP | Efficiency *Estimated versus Wanted* [score] | Monitor Status MS | Evaluation (acceptability) | Comments (decision for improvement?) |
|---|---|---|---|---|
| **0 Very Small** | EE ≥ WE [4 , 3]* | - | 0 | No need for improvement |
| | EE < WE [2] | - | 1 | Can be considered |
| **1 Small** | EE ≥ WE [4 , 3] | - | 0 | No need for improvement |
| | EE < WE [2] | 0 | 2 | Is recommended; prevent degrading of SF |
| | | 1-2 | 1 | Can be considered |
| **2 Rather large** | EE ≥ WE [4 , 3] | 0-1 | 2 | Is recommended; prevent degrading of SF |
| | | 2 | 0 | No need for improvement |
| | EE < WE [2] | 0 | 3 | Is essential |
| | | 1-2 | 2 | Is recommended; prevent degrading of SF |
| | EE << WE [1] | - | 3 | Is essential |
| **3 Large** | EE ≥ WE [4, 3] | 2 | 1 | Can be considered |
| | | 1 | 2 | Is recommended; prevent degrading of SF |
| | | 0 | 3 | Is essential |
| | EE < WE [2] | 2 | 2 | Is recommended; prevent degrading of SF |
| | | 0-1 | 3 | Is essential |
| | EE << WE [1] | 0-1 | 4 | Urgent improvement; intolerable situation |
| | | 2 | 3 | Is essential |

*(*) the scores in brackets are explained next page; this results from the decision made at Renova, in which the efficiency "Wanted =3"*

At this stage, it should be noted that the efficiency scores in brackets, which are registered in the respective column of table 3.13, were added in this particular work to provide a final score for "efficiency", after comparing estimated against wanted. In this study, the hosting company (Renova) has set up “3” (> 99%) as their Wanted Efficiency (WE) threshold for all SFs in production Line H4. Thus:

- If the Estimated Efficiency (EE) is better/higher than the Wanted Efficiency (WE) - the overall "Efficiency" attribute gets maximum score (4);
- If the EE is equal to WE - it gets score "3" (i.e., same as desired);
- If the EE is lower than the WE - it gets score "2";
- If the EE is much lower than the WE - it gets score "1" (minimum score).

However, from the moment one decides the level Wanted (WE), the logical notation (EE vs. WE) may also be used directly for making a judgment.

# 4. Case Study

This chapter presents the host company and gives a brief description of the processes chosen to constitute the case-study.

## 4.1 *Renova (company description)*

Renova is a manufacturing company specialized in the production of paper tissue, printing paper and packaging. It is a private Portuguese company created in 1939, situated in Torres Novas. It possesses two industrial units, presently employing about 650 workers, split by the two plants.

Renova is both a company and a brand name, where the environment, safety, quality and innovation are in their strategic concerns. With respect to the environmental policy, they are well placed when comparing to their similar European competitors.

In 1999, Renova was the first company of its sector to obtain the environmental certification according to the norm ISO14001, and in 2004, the certification of EMAS (Eco-Management and Audit Scheme). The operations safety and wellbeing of their workers took Renova, in 2004, to obtain a Safety and Health at Work certification, according to the norm OHSAS 18001. Also in 2004, Renova received the certification on quality management, ISO 9001:2000, ISO 17025.

In 2007 new challenges arise, which took Renova to obtain another two certificates, one for food safety, according to referential BRC/IoP, and the other in investigation systems, development and innovation, according to NP 4457 (2007, related to "investigation management, development and innovation").

Within the Portuguese social-economical context, Renova is currently the market leader in all the paper tissue products. In Spain is leader in the napkin segment and it is also present in France, Belgium, Luxemburg and the United States markets.

Renova's administration recognizes Health and Safety at Work as a priority of management; they believe that operational excellence and organization discipline are only possible with an effective protection of their employees, environment and material resources.

The implementation of continuous improvement on health and safety levels, involves the creation of a solid safety culture, which is accomplished by prevention, regular risk assessments and also by implementing a set of rules and guidance that are mandatory to all employees. In order to manage safety and to define responsibilities at different levels, Renova has created a structure that assigns responsibility in three ways: PEI ("*Plano de Emergência Interno*" – Internal Emergency Plan), STS ("*Serviços Técnicos de Segurança*" – Technical Security Services) and SHST ("*Serviços de Saúde e Segurança no Trabalho*" – Health and Safety at Work Services).

Figure 4.1 shows the hierarchical organization of the Renova's Services for Health and Safety at Work.

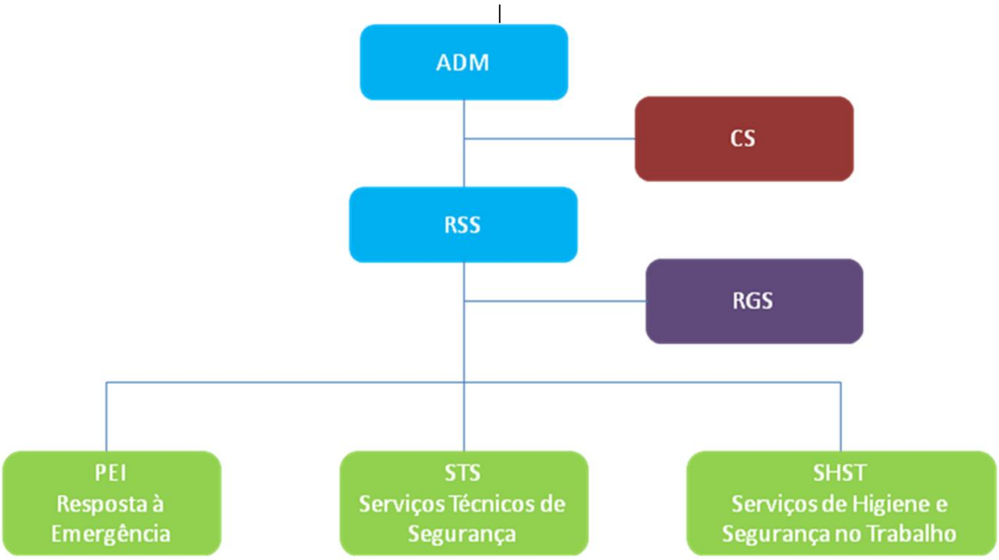


**Figure 4.1 - Safety and Health at work services of Renova (supplied by Renova, 2011)**

The administration (ADM), the responsible for safety services (RSS) and the responsible for the safety management system (RGS) are lead by a single person each; in contrast the safety commission (CS) and STS involves seven people, the SHST services involve about fifty and PEI engages around a hundred and fifty persons. However, all those people accumulate functions; they are also production operators, logistic operators, administrative personnel, etc. The only person who works exclusively on safety issues is the responsible for the RGS.

## 4.2 *Process Description*

The production process splits into four divisions: Recycling Division (DIRE), where the old paper is transformed in fiber to be used as raw material; Fabrication Division (DIFA), where it is processed the paper sheet; Transformation Division (DITA), where the paper sheet is transformed into a range of products for home, sanitary and industrial use; and Sanitary Product Division (DISA), a specialized sector for production of women sanitary protection.

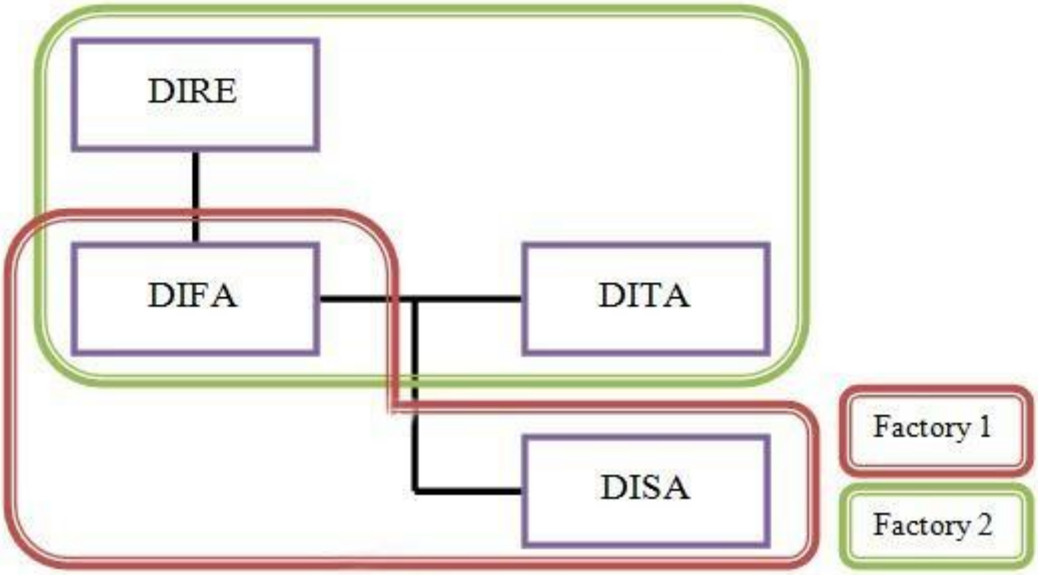


**Figure 4.2 - Renova's Production Process and respective factories**

Factory 1 possesses part of the fabrication division (one paper tissue machine and two printing/writing *100% recycled* paper). DISA division (sanitary products) belongs here. Factory 2 has the recycling division, part of the fabrication division (two paper tissue production machines) and the transformation division.

**Recycling Division (DIRE)**

The aim of DIRE is to obtain high quality recycled fibers, starting from selections of “old paper”. The recycling consists of withdrawing from the “old paper” all the non fiber materials, like reinforcing agents (carbonates, silica, etc.), ink and other contaminants resulted from the use of paper. This material is eliminated by means of sequential rejection using, simultaneously, four different processes: “*hidrociclonagem*”, screening, washing and floatation. The referred processes are based on the physical-chemical properties that differentiate the fiber contaminants, such as form, size, density and electrostatic affinity. In the process there are two whitening phases (oxidative and reductive) that allows increasing the whiteness of the recycled pulp.

**Fabrication Division (DIFA)**

The fabrication division of factory 2 has two machines for the production of paper tissue. This paper has an incredible smooth touch, flexible, of high softness and absorption; these properties can be obtained through a specific process, which is based on a very careful choice of components and in the shaping of parallel transversal micro-waves across the production line (called "*crepe ratio*"). The waves are formed by a blade, strategically placed to withdraw the paper from the drying cylinder with the desired effect.

This type of paper has several kinds of use, although the domestic and sanitary applications are predominant; it can also be used to make packages and filters due to its softness and permeability. The fabrication can be made in both machines in four phases: pulp preparation, sheet formation, drying and "*crepe ratio*" formation.

The pulp preparation - the whole set of operations described - precedes the sheet fabrication and begins with the disintegration of dry pulp and ends with the machine feeding (for sheet fabrication). The fabrication of the sheet sub-product involves another set of operations, such as, centrifugation, vacuum, pressing and drying. The sheet fabrication ends with winding of either single or several sheets into standard-sized reels.

**Transformation Division (DITA)**

The transformation division's activity is divided into three convergent transformation areas: folds, multipurpose rolls and rolls of toilet paper.

The lines of this division receive the paper in standard-sized reels, according to the type of product and line, directly supplied by the fabrication division and partly by the automatic warehouse. These production lines are flexible, able to produce more than one final product, with just a few mechanical, flow, or raw material changes.

Generally, all the production machines of this division are composed of a winder and a packager. If the product produced in a certain line is aimed for bags, the line still has a bag machine and palletizing robot. The object of study of this work is one of those lines, which is detailed below.

**Production Line H4 - description**

The production line studied in this work is known as H4; this is a transformation process of large paper tissue reels into toilet paper rolls. Not all the processes (or production phases) were analyzed, but only the most significant for safety purposes. The main processes are listed and explained below.

1. Raw material loading – process in which the raw material is loaded to the transformation machine. In this case, the raw material consists of a large paper reel of about 2 000kg, and 3m width. It is performed by a totally automated machine known as AGV (Automated Guided Vehicle), and after its transportation to the AGV table, the paper reel is loaded to the unwinding machine with a Rolling Bridge (LT2) guided, manually, by a worker (Fig. 4.3);

**Figure 4.3 - Raw material loading**

2. Unwinding the paper tissue reel – the worker makes an eye control of the position of the sheet in the machine; the paper reel must be located centering the paper with the cutting blade. In this machine, there are two reels unwinding the paper simultaneously, so that can be made the “double sheet” toilet paper;

3. Micro and Macro Embossing – the paper is forwarded to the embossing machine, where it suffers a change in its texture and union of sheets by adding glue and macro embossing;

4. Edge embossing – the paper sheets are united by mechanical pressure in the surface by a set of roulettes over a steel roller;

5. Perforation – formation of the tear line in the paper roll sheet;

6. Winding – winding the paper on the core, controlling the relation between winding speed and its diameter. The cores are loaded in this part of the process;

7. Transversal paper cut – after the roll has reached its proper dimension (diameter), the last sheet is transversally cut;

8. Gluing the last sheet – sealing glue application to the last sheet of paper;

9. Log intermediate storage – machine where the logs are stored before being sawed into minor pieces (see Fig. 4.4);

**Figure 4.4 - Log accumulation**

10. Transversal cut of logs – the log is sliced into equal parts creating the (toilet) paper rolls by a fast rotating saw - placed inside a safety metal cabin. The trims (residues) resulted from the cutting process are dropped into a conveyor belt, perpendicular to the saw, and lead to a waste recycling container. The worker controls the roll cut and format by visual inspection (from outside the encapsulating cabin);

11. Primary package (Packaging) – applying a film of propylene to the package. There is a visual control of the film position relatively to the roll set;

12. Secondary package (Bagging) – applying a second film of propylene to a predefined set of packages, creating a selling unit to the public (bag). A visual control is performed by the worker before placing the bags on the pallets, for further transport to the warehouse;

13. Final product – a final quality control is made to the product, by sampling.

In addition to this, the process of forming the inner core was also analyzed. It consists of a set of other processes, in which the final one (Loading of core to the transformation machine) occurs between the perforation and winding processes (*c.f.* 5 and 6). These processes are listed below:

14. Loading raw material (card board reel);

15. Unwinding the material – unwinding the cardboard roll;

16. Printing brand in core;

17. Shaft lubrication – lubrication of the winding shaft;

18. Glue application;

19. Forming the core – forming the core, which will function as a physical support for winding the paper tissue sheet;

20. Scent application;

21. Longitudinal cut of core – predefined dimensions (see Fig. 4.5);

22. Loading of core to transformation machine.

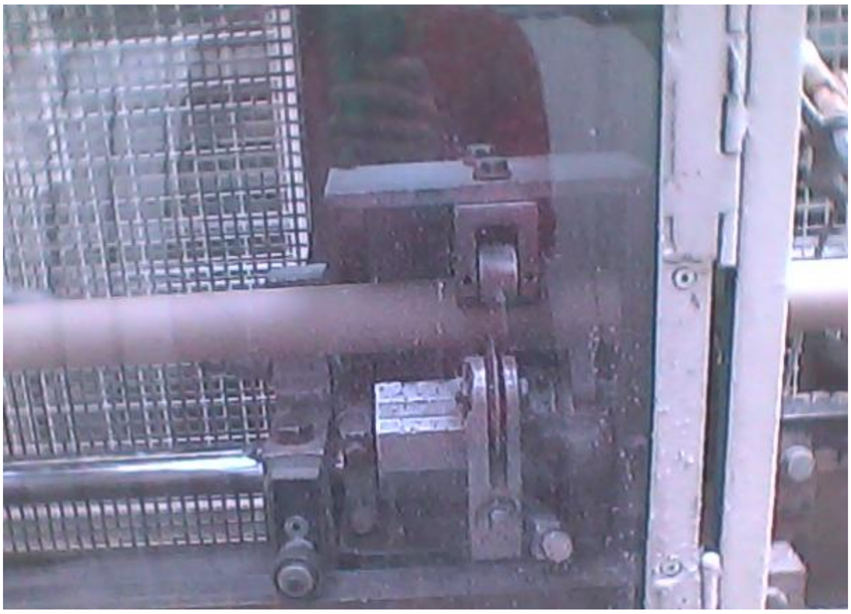

**Figure 4.5 - Longitudinal cut of core**

The entire production line (22 processes) was observed for a week, after which the author, together with a group of Renova's engineers, decided to make a full safety study of *only two processes*: Raw material loading (#1) and Transversal cut of logs (#10), since time was a constraint and these two were considered the most interesting ones as explained next.

The tables with the full results of the two processes studied are given in Appendix I and II respectively. However, two SF will be thoroughly analyzed and discussed in the next chapter, essentially to illustrate the complete application of the SFA methodology.

# 5. Application of SFA method

This chapter describes the SFA application to a set of safety functions identified and analyzed in two of the processes of line H4, aiming to offer a deeper understanding of the SFA procedure and its value to safety improvement. The processes chosen, as mentioned in the previous chapter, are the **raw material loading** (#1) and **the transversal cut of logs** (#10). As already mentioned in chapter 3, this choice was based on the number and type of hazards identified. Moreover, these two processes were identified by Renova's risk assessment (*c.f.* chapter 3.2) as having *high level risks* (scored over 360).

## 5.1 *First Process – Raw material loading*

This includes the transportation of the raw material (large reels) by an AGV and the transference of such load to the AGV table. Next, the reels, weighing around 2 Ton each, are picked or dropped by two different Lifting Devices: a Lifting Truck (LT1) equipped with a spindle and a Rolling Bridge (type of overhead traveling crane - LT2).

**Step 1- Hazard Selection**

The hazard selection resulted from different elements, such as: individual observations of the process, analyses of the "*hazard identification and risk control map for line H4*" provided by Renova, and discussions with workers of that line.  Within this process, each equipment/infra-structure was separately analyzed and each one has one or more hazards associated, as is shown in the evaluation table A1 of Appendix I.

**Step 2- Identification of safety functions**

The identification of the safety functions was firstly made through the observation of the work cycle, and then self questioning, for example: *what is the likelihood of an accident being kept low?* or *How are consequences kept to a low level?*. Other identification methods included "text analyses" of the same document referred in step 1 (*hazard identification and risk control map for line H4*), or discussions with workers and middle-managers of line H4 and by analyzing the legal requirements for use of equipment and machinery presented in chapter 2.2. This resulted in the identification of **47 safety functions** (Appendix I), some of which are illustrated in table 5.1. The colored SF is the example that will be discussed later in more detail.

**Table 5.1 – Example of the safety function evaluation for the process raw material loading**

| Equipment or infra-structure | Hazard / Risk | Safety Function: Type | Safety Function: Description | Intention | Evaluation Process: Importance | Evaluation Process: Efficiency | Evaluation Process: Monitoring Status | Evaluation Process: Acceptance level | Code (Recom) |
|---|---|---|---|---|---|---|---|---|---|
| AGV (load = paper reel; app. 2T) | Mechanical handling of loads | Containement | Cover bars and speed to prevent fall of load | 1 | 2 | 4 | 2 | 0 | 1.1 |
| | • Fall of load | Automatic control | Photoelectric sensors in AGV (proximity of obstacles) | 3 | 2 | 3 | 2 | 0 | 1.2 |
| | • Collision of AGV with person | | Sound and light warnings to indicate the presence/arrival of AGV | 3 | 2 | 3 | 2 | 0 | 1.3 |
| | | Reduction of consequences | First aid team (certified); 24h | 3 | 2 | 3 | 2 | 0 | 1.4 |
| | | | First and Second intervention teams of Renova | 3 | 1 | 4 | 2 | 0 | 1.22 |
| | | Procedures and routines (formal and informal) | Maintenance manual | 2 | 2 | 3 | 2 | 0 | 1.5 |
| | | | Circulation rules to prevent collision with person | 3 | 2 | 3 | 1 | 2 | 1.6 |
| | | Management/Organizational | Equipment verification reports; maintenance policy | 2 | 2 | 3 | 2 | 0 | 1.7 |
| LT1 (lifting truck - spindle) | Mechanical handling of loads | Containement | Solid structure and speed to prevent fall of load | 3 | 2 | 3 | 2 | 0 | 1.1 |
| | • Same as above for AGV | Automatic control | Equipment start-up only with voluntary action | 3 | 3 | 3 | 2 | 1 | 1.8 |
| | | Reduction of consequences | First aid team (certified); 24h | 3 | 2 | 3 | 2 | 0 | 1.4 |
| | | | First and Second intervention teams of Renova | 3 | 1 | 4 | 2 | 0 | 1.22 |
| | (unsafe handling of load) | Procedures and routines (formal and informal) | Maintenance manual | 2 | 2 | 3 | 2 | 0 | 1.5 |
| | | | Circulation rules to prevent collision | 3 | 3 | 2 | 2 | 2 | 1.9 |
| | | | LT1 driver training | 2 | 3 | 4 | 2 | 1 | 1.10 |
| | | | Maintenance operators training in safety | 3 | 3 | 3 | 2 | 1 | 1.11 |
| | | Management/Organizational | Equipment verification reports; maintenance policy | 2 | 2 | 3 | 2 | 0 | 1.7 |
| LT2 (Rolling bridge) | Mechanical handling of loads | Containement | Not applicable; Not identified | - | - | - | - | - | - |
| | • Same as above for LT1; | Automatic control | Control systems clearly identifiable | 2 | 2 | 4 | 2 | 0 | 1.12 |
| | | | Equipment start-up only with voluntary action | 2 | 3 | 3 | 2 | 1 | 1.8 |
| | (unsafe handling of load) | Reduction of consequences | First aid team (certified); 24h | 3 | 2 | 3 | 2 | 0 | 1.4 |
| | | | First and Second intervention teams of Renova | 3 | 1 | 4 | 2 | 0 | 1.22 |
| | | Procedures and routines (formal and informal) | Circulation rules to prevent collision | 3 | 3 | 3 | 2 | 1 | 1.9 |
| | | | LT2 Operator training in safety | 3 | 3 | 4 | 2 | 1 | 1.13 |
| | | | Maintenance operators training in safety | 3 | 3 | 3 | 2 | 1 | 1.11 |
| | | Management/Organizational | Equipment verification reports; maintenance policy | 2 | 2 | 3 | 2 | 0 | 1.7 |
| | Noise exposure<br>• Hearing damage<br>Projection of hydraulic fluid<br>• Eyes damage | Not analized; risk score ≤ 360 | | N/A | | | | | |

**Step 3- Structuring and classification of safety functions**

For each equipment there are one or more hazards, so for each one, the safety functions were divided into five classes: *1- containment, 2- automatic control, 3- reduce of consequences, 4- procedures and routines (formal and informal) and 5- management/organizational*. The class *procedures/routines* integrates both the formal and informal procedures, because it was difficult to distinguish between one another in many cases. After this structuring, the safety functions are sorted and ready to be evaluated.

**Step 4- Evaluation of safety functions**

The evaluation stage combines five characteristics that help to evaluate whether a safety function is acceptable or not: *Intention, Importance, Efficiency, Monitoring Status and Acceptability*. This stage was carried out with the help of two experienced Renova's engineers in a brainstorming session, so any question or doubt regarding more specific safety functions could be clarified at that moment and discussed immediately, aiming to attain more appropriate decisions (consensual). Table 5.1 also shows the results obtained from the evaluation of safety functions.

The next paragraphs will explain, in detail, the evaluation of the safety function highlighted in the table (*Photoelectric sensors in AGV (proximity of obstacles)*); this SF was classified as "automatic control" and it concerns the control of the hazard "mechanical handling of loads" associated with the AGV (Figure 5.1).

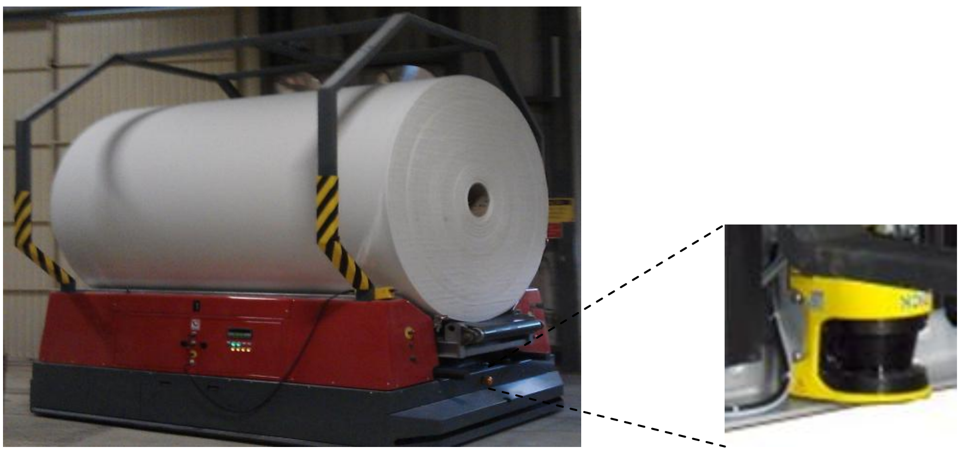

**Figure 5.1 – AGV transporting raw material + photoelectric sensor**

So, the evaluation was made as follows:

1. The **intention** (an informative attribute) of the *photoelectric sensors* was classified as "3", because these sensors are intended to provide safety;

2. This safety function has a "rather large" influence on safety, closely connected to accident or size of consequences because the photoelectric sensors are what stops the AGV and prevents collision with persons or objects; its **importance** was scored "**2**";

3. The **efficiency** was classified by looking at the error frequency column in table 3.10. There are two kinds of efficiency concepts (Estimated and Wanted), the *Wanted Efficiency,* or "target", refers to the expectations of Renova - so that one can give a value to the *Estimated Efficiency* by comparison. As mentioned before, Renova wants to have (WE) a high efficiency (scored "3") in all SFs of this line. In the case of the photoelectric sensors, the analysts considered *wanted efficiency* as being equal to the *estimated efficiency.* So it was scored "**3**";

4. As for the **monitoring status**, this function is already monitored for its purpose and meets the requirements, so the classification was given as "**MS2**" (scored 2).

In the light of the above, the **acceptance level** can be classified as *Acceptable* ("**0**") with *no need for improvement*. To classify the acceptance level, table 3.13, which works as a decision tree, came very useful to assess the combinations of criteria. In short, this safety function is working correctly and according to its purpose.

**Step 5- Propose improvements**

Generally speaking, to improve efficiency or eliminate weak points of the safety functions, improvements must be considered and suggested. The acceptability criterion, which depends on the factors analyzed previously (Importance, Efficiency and Monitor Status), presented in the last column of table 5.1, should lead to an action plan. In this particular example - concerning the *photoelectric sensors* - the action plan is simply to *maintain the current status* (Table 5.2), since it is working well. The whole set of recommendations (for all other items) are presented in Appendix I (Table A2).

**Table 5.2 - Example of corrective actions proposed for the process raw material loading**

| Code | Requirements of the safety functions | Corrective actions proposed |
|---|---|---|
| **1.1** | The structure (cover bars) of the equipment must be robust to prevent unwanted events as the fall of heavy load; AGV speed must be controlled. | Maintain the current status of functioning and its monitoring. |
| **1.2** | The AGV must have sensors to identify the presence of obstacles or people in order to stop vehicle when necessary. | Maintain the current status of functioning and its monitoring. |
| **1.3** | The AGV must have sound or light warnings to indicate its presence/arrival, so operators can travel safety through the factory. | Maintain the current status of functioning and its monitoring. |
| **1.4** | There must be a first aid certified team ready to act over 24h in the factory. | Maintain the current status of functioning and its monitoring. |
| **1.5** | The AGV maintenance manual must have all the necessary and important information (in Portuguese). | Nothing to improve. The manuals are all in Portuguese and updated. |
| **1.6** | There must be well defined circulation rules to prevent collision with person. | Review and improve the circulation rules and signs in areas where the likelihood of accident is higher. |
| **1.7** | The equipment verification reports must be updated according to any new needs - and the maintenance policy reviewed. | Maintain the current status of functioning and its monitoring. |
| **1.8** | A voluntary action must be applied over a control to start equipments after a stop of any kind, unless the stop results from a normal sequence or an automatic work cycle (legal requirement: Art. 12, DL 50/2005). | Given importance “3” of this SF, an improvement can be considered in order to update the safety switch that starts the equipment (start-up switch) |
| **1.9** | There must be well defined circulation rules to prevent collision with elements. | Improvement of this SF is recommended; in addition, the rules and circulation routes should be reviewed after any changes in the factory layout. |
| **1.10** | On equipments with specific risks, the employer must take special precautions so that the use of that equipment is only made by a qualified operator for the corresponding activity (legal requirement: Art. 5, DL 50/2005). | Maintain the training of drivers updated by revising qualifications every year. |

## 5.2 *Second Process – Transversal cut of log*

This process includes the slicing of the log, performed by a *hi-speed cutting saw*, into equal parts, and the trims drop into a conveyor belt heading to a waste recycling container.

**Step 1- Hazard Selection**

The hazard selection was made as in the previous example and some of the hazards identified were quite similar. However, a very harmful cutting device (saw) is now part of this process, to which different hazards are associated with, as registered in the analysis table A3 of Appendix II. In this second example the hazard illustrated is the *hi-speed cutting saw*.

**Step 2- Identification of safety functions**

The identification of the applicable safety functions followed exactly the same procedure described before within the first example. The analysis of this second process (*transversal cut of log*) revealed **36 safety functions**, some of which are listed in table 5.3 for illustration purposes. Once again, one particular SF was chosen for demonstration and will be discussed in more detail.

**Step 3- Structuring and classification of safety functions**

The 36 safety functions were again divided into five classes: *1- containment, 2- automatic control, 3- reduce of consequences, 4- procedures and routines (formal and informal) and 5- management/organizational*. The class *procedures/routines* still integrates both the formal and informal procedures for the same reason given before (difficult to distinguish between them). After this structuring the safety functions were sorted and ready to be evaluated.

**Step 4- Evaluation of safety functions**

This stage was made in collaboration with two experienced engineers during a second brainstorming meeting. This time the analysts went to the production line and watched the process once again; any question or doubt regarding more specific safety functions could be clarified at that moment and discussed at the place. Table 5.3 shows the results obtained from the evaluation of these new set of safety functions.

The safety function highlighted in the table "*barriers preventing walkthrough over the conveyor"*, concerning the Trim Conveyor Belt, was classified as a "containment" type with relation to the risk of mechanical contact (Figure 5.2). In this case, however, the SF does not exist (absent SF) and therefore it cannot be seen in the photo (Figure 5.2).

**Figure 5.2 - Trim Conveyor belt**

The evaluation was made as follows:

1. The **intention** of this barrier - if it existed - should be scored "**3**", i.e., specifically intended for safety reasons.

2. The **importance** of this safety function should be considered "rather large", since it would prevent operators from losing their step (or balance) when crossing the conveyor, or even block the crossing (wrong) action, which seems to occur quite frequently; so **importance** is "**2**";

3. The overall **efficiency** was scored "0" because it does not exist;

As for the **monitoring status**, since this function does not exist yet, it does not meet any requirements; its classification was "**MS0**".

In the light of the above, the **acceptance level** can be classified as *Not Acceptable* ("**3**"), and in this case *improving the safety function is essential*. Table 3.12 was also used to assess and classify the acceptance level.

**Table 5.3 - Example of the safety function evaluation for the process transversal cut of log**

| Equipment or infra-structure | Hazard / Risk | Safety Function: Type | Safety Function: Description | Intention | Evaluation Process: Importance | Efficiency | Monitoring | Acceptance level | Code (Recom) |
|---|---|---|---|---|---|---|---|---|---|
| Saw cabine | Contact with sharp elements | Containement | Physical barriers preventing access to cutting saw | 3 | 3 | 4 | 2 | 1 | 1.1 |
| | • Pinching, crushing, cutting | | Protection of moving elements | 3 | 3 | 2 | 2 | 2 | 1.2 |
| | | | Accessibility to the cabine | 3 | 3 | 4 | 2 | 1 | 1.3 |
| | | | Use of EPI's when accessing the cabine | 3 | 2 | 4 | 2 | 0 | 1.4 |
| | | Automatic control | Safety Switch | 3 | 2 | 4 | 2 | 0 | 1.5 |
| | | | Equipment start-up only with voluntary action | 3 | 3 | 4 | 2 | 1 | 1.6 |
| | | | Control devices far from dangerous areas | 3 | 2 | 4 | 2 | 0 | 1.7 |
| | | Reduction of consequences | First aid team (certified); 24h | 3 | 2 | 3 | 2 | 0 | 1.8 |
| | | | First and Second intervention teams of Renova | 3 | 1 | 4 | 2 | 0 | 1.9 |
| | | Procedures and routines (formal and informal) | Periodic preventive maintenace | 2 | 2 | 3 | 2 | 0 | 1.10 |
| | | | Safety signals informing the presence of cutting element | 3 | 2 | 2 | 2 | 2 | 1.11 |
| | | | Maintenance operators training in safety | 3 | 3 | 3 | 2 | 1 | 1.12 |
| | | Management/Organizational | Equipment verification reports; maintenance policy | 2 | 2 | 3 | 2 | 0 | 1.13 |
| | Material accumulation, paper dust | Containement | Extracting system | 3 | 3 | 2 | 2 | 2 | 1.14 |
| | | | Electrical wiring isolation | 3 | 2 | 3 | 2 | 0 | 1.15 |
| | • Fire | Automatic control | Smoke detectors | 3 | 3 | 2 | 2 | 2 | 1.16 |
| | | Reduction of consequences | First aid team (certified); 24h | 3 | 2 | 3 | 2 | 0 | 1.8 |
| | | | First and Second intervention teams of Renova | 3 | 1 | 4 | 2 | 0 | 1.9 |
| | | Procedures and routines (formal and informal) | Reports analyzing particles of dust for fire prevention | 3 | 3 | 4 | 2 | 1 | 1.17 |
| | | | Thermographic tests | 3 | 2 | 2 | 0 | 3 | 1.18 |
| | | | Periodic cleaning | 2 | 2 | 3 | 2 | 0 | 1.19 |
| | | Management/Organizational | Equipment verification reports; maintenance policy | 2 | 2 | 3 | 2 | 0 | 1.13 |
| Trim Conveyor Belt | Mechanical contact | Containement | Barriers preventing walkthrough over the trim conveyor | 3 | 2 | 0 | 0 | 3 | 1.20 |
| | • Pinching, crushing, cutting | | Protection of moving elements | 3 | 3 | 2 | 2 | 2 | 1.2 |
| | | Automatic control | Equipment start-up only with voluntary action | 3 | 3 | 3 | 2 | 1 | 1.6 |
| | | | Safety Switch | 3 | 2 | 3 | 2 | 0 | 1.5 |
| | | Reduction of consequences | First aid team (certified); 24h | 3 | 2 | 3 | 2 | 0 | 1.8 |
| | | | First and Second intervention teams of Renova | 3 | 1 | 4 | 2 | 0 | 1.9 |
| | | Procedures and routines (formal and informal) | Periodic preventive maintenace | 2 | 2 | 4 | 2 | 0 | 1.10 |
| | | Management/Organizational | Equipment verification reports; maintenance policy | 2 | 2 | 3 | 2 | 0 | 1.13 |
| Conveyor exiting the saw | Removal of product; line in motion • Pinching, crushing, cutting | Not analized; risk score ≤360 | | N/A | | | | | |

**Step 5- Propose Improvements**

The acceptability criterion depends on the same factors presented in the other process, and it is shown in the last column of table 5.3; this criterion leads to an action plan that aims at improving safety. Such plan of action is comprised by a set of recommendations, as suggested in table 5.4.

In the example discussed here, the SF in question (*barriers preventing walkthrough over the conveyor*) does not exist and it should be implemented.

The design of a physical barrier (new SF) might consider two alternative solutions:

1- to prevent the crossing at all; in such case workers need to go around a couple of meters to reach the other side. In fact, this is what they are expected to do right now, but they tend to adopt a dangerous behavior and simply jump or cross over the conveyer belt.

2- to create a crosswalk bridge over the conveyer, giving operators the possibility to keep crossing it, but in a safer way.

The second option seems to be preferable, but this has not yet been decided.

## 5.3 *Synthesis of Chapter*

The contents of this chapter are merely illustrative, since it describes the five steps of SFA approach in a detailed way, applied to two different processes. The evaluation phase, in particular, was demonstrated through the application of each criterion (*Intention*, *Importance*, *Efficiency*, *Monitoring Status* and the *Acceptability*).

The first example shows a “good” safety function, which does not need improvements; by contrast, the second one identifies an “absent” safety function that needs to be designed and implemented from scratch.

**Table 5.4 - Example of corrective actions proposed for the process transversal cut of log**

| Code | Requirements of the safety functions | Corrective actions proposed |
|---|---|---|
| **1.13** | The equipment verification reports must be updated according to any new needs - and the maintenance policy reviewed. | Maintain the current status of functioning and its monitoring. |
| **1.14** | Work equipments must have efficient retention or extraction devices located near the focus point (Art. 15, DL 50/2005). | Improvement of extractors is recommended, despite their reasonably good condition; Monitoring is essential and should not downgrade. |
| **1.15** | All the (electrical) active parts of the installation must be completely isolated; their removal should only be possible through destruction. | Maintain the current status of functioning and its monitoring. |
| **1.16** | The warning devices (from smoke detectors) must be clearly heard and easily understood without ambiguity (Art. 18, DL 50/2005). The saw cabin must have a smoke detector inside. | Improvement is recommended. |
| **1.17** | The particles of dust and their concentration in the air must be analyzed periodically (for fire protection). | Maintain the frequency of the tests and reports. However, an improvement can be considered. This needs to be discussed with management to find out the best cost-benefit solution. |
| **1.18** | Make thermo-graphic tests in order to identify possible hot spots that may originate fire (source). | It is essential to implement the thermo-graphic tests in the cabin saw. Run these tests at least twice a year. |
| **1.19** | The saw cabin must be periodically cleaned in order to eliminate dust accumulation. | Maintain the periodic cleaning once a month; keep records of this activity. |
| **1.20** | The moving elements liable of causing accidents by mechanical contact must have protecting devices with robustness that stop the access to dangerous areas, or devices that interpose the movement of elements before they access those areas. They must be situated in a secure distance and must not limit the work cycle observation (Art. 16, DL 50/2005). | Improvement is essential.<br>It is essential to create a physical barrier to prevent walking through (or over) the trim conveyor belt, or, if feasible, create a crosswalk bridge over the conveyor. |
| **1.21** | The dust removal system (main extraction system) must have a solid structure in order to prevent any leak. | Maintain the current status of functioning and its monitoring. |

# 6. Discussion of Results

In this chapter, the most significant results of this safety analysis are highlighted and discussed.

## 6.*1 Discussion of results of the process "raw material loading"*

As stated in the previous chapter, **47 safety functions** were identified in the process "raw material loading". These SF were structured and classified within five different groups and the details of the analysis are given in Appendix I. Table 6.1 shows a synthesis of the results.

**Table 6.1 - Synthesis of safety functions, by hazard and group of SF in the "raw material loading"**

| Group \ Hazard | Safety Functions | | |
|---|---|---|---|
| | Mechanical handling of loads | Fire, electricity, projection of particles and paper dust | **Total** |
| **Containment** | 3 | 3 | **6** |
| **Automatic control** | 6 | 2 | **8** |
| **Reduction of consequences** | 8 | 4 | **12** |
| **Procedures and routines (formal and informal)** | 10 | 3 | **13** |
| **Management/Organizational** | 4 | 4 | **8** |
| **Total** | **31** | **16** | **47** |

By analyzing the table above, it can be concluded that the *mechanical handling of loads* has around 66% of the total safety functions, while all the remaining relevant hazards, including *fire, electricity, projection of particles and paper dust* have about 34%. The later category of hazard(s) had been identified only in one equipment/infra-structure (the AGV Table), whereas the hazard *mechanical handling of loads* exists in three different equipments.

In spite of this relative weight in the line studied (Line H4; 66% vs 34%), the hazards clustered in category *fire, electricity, projection of particles and paper dust* play an important role on the overall safety of Renova's plant because this is a paper transformation company. Another important fact that can be taken from table 6.1 is that this methodology allows to identify (and to assess) two important categories that are often overlooked: the *procedures and routines* as well as the *management/organizational* functions, showing a significant number of SFs within these groups. This is an advantage of SFA method, which highlights the need to account for such types of SF.

**Table 6.2 - Synthesis of the proposed recommendations in the "raw material loading"**

| Recommendations / Group | Safety Functions | | | |
|---|---|---|---|---|
| | OK, Maintain | Needs Improvement | Improvement is not practicable | **Total** |
| **Containment** | 4 | 1 | 1 | **6** |
| **Automatic control** | 5 | 2 | 1 | **8** |
| **Reduction of consequences** | 12 | 0 | 0 | **12** |
| **Procedures and routines (formal and informal)** | 3 | 10 | 0 | **13** |
| **Management/Organizational** | 8 | 0 | 0 | **8** |
| **Total** | **32** | **13** | **2** | **47** |

As explained in Chapter 4, Renova is acknowledged for their concern on health and safety at work, having already received two certificates is this field. As such, the results summarized in table 6.2 seem predictable; it is noteworthy that for the majority of the SF assessed (32 out of 47; 68%), the recommendation consists simply of "Maintain" the current status. A smaller amount (13 SF; 27%) need improvement (*c.f.* Tables A2 - Appendix I), whereas two non-existing SF would be useful, but their implementation was considered not practicable. One example concerns "**barriers to prevent access of people when loading**" the AGV table, but such barrier would also obstruct the AGV access to the table.

Overall, these results, together with the absence of work injuries, indicate a good performance of the safety functions implemented in this company. This conclusion corroborates an earlier study made in the same plant but in a different process (Carracinha, 2009), in which the original version of the SFA method was applied and proved to be useful for identifying improvement opportunities.

## 6.2 *Discussion of results of the process "transversal cut of log"*

This section summarizes and discusses the relevant results concerning the analysis of the process *transversal cut of log*. In this case, **36 safety functions** were assessed, after being structured and classified into the five main groups, as summarized in table 6.3.

**Table 6.3 - Synthesis of safety functions, by hazard and group of SF in the "transversal cut of log"**

| Group \ Hazard | Safety Functions | | | | |
|---|---|---|---|---|---|
| | Contact with sharp elements | Fire | Mechanical contact | Particles and dust exposure | **Total** |
| **Containment** | 4 | 2 | 2 | 1 | **9** |
| **Automatic control** | 3 | 1 | 2 | 1 | **7** |
| **Reduction of consequences** | 2 | 2 | 2 | 2 | **8** |
| **Procedures and routines (formal and informal)** | 3 | 3 | 1 | 1 | **8** |
| **Management/Organizational** | 1 | 1 | 1 | 1 | **4** |
| **Total** | **13** | **9** | **8** | **6** | **36** |

From this table, one can infer that the hazard *Contact with sharp elements* has a higher number of safety functions (13), fact that can be explained by the extra care that operators must have in this process. The cutting saw is inside an acrylic cabin (Containment safety function), however any contact with the saw can produce harm if not properly done (e.g.: cleaning, maintenance, etc.). In this process, controlling *Fire hazards* depends on a significant number of safety functions (9), some of which are technical, but almost half of them concern procedures, routines and organizational issues; being a paper products manufacturer, *fire safety* in Renova represents a high concern and a safety priority.

Finally, hazards concerning *Mechanical contact* and *Particles and dust exposure*, are associated with 8 and 6 safety functions respectively. As illustrated in Chapter 5, one of these SF is a “missing barrier” on the trim conveyer belt, i.e., it does not exist at the moment but the analysis revealed it to be relevant.

**Table 6.4 - Synthesis of the proposed recommendations to the “transversal cut of log”**

| Recommendations / Group | Safety Functions | | | |
|---|---|---|---|---|
| | OK, Maintain | Needs Improvement | Improvement is not practicable | **Total** |
| **Containment** | 3 | 6 | 0 | **9** |
| **Automatic control** | 3 | 4 | 0 | **7** |
| **Reduction of consequences** | 8 | 0 | 0 | **8** |
| **Procedures and routines (formal and informal)** | 4 | 4 | 0 | **8** |
| **Management/Organizational** | 4 | 0 | 0 | **4** |
| **Total** | **22** | **14** | **0** | **36** |

The complete set of results is presented in Appendix II, but the summary table 6.4 reveals, once again, that most SFs (61%) do not need improvement in contrast with a smaller number (14 SF; 39%) that require attention. However some of these actions belong to the category “improvement can be considered” and are designed just to prevent degrading (or promote upgrading) of the respective SF; some “safety signs”, for instance, are included here.

In this second analysis nothing was considered as *Not practicable* in terms of implementation.

## 6.3 *Synthesis of Chapter*

This field application of the new version of SFA method, helped to assess 47 SF in the process “*raw material loading*” and another 36 in the process “*transversal cut of log*”. Of these, 13 and 14 SF, respectively, revealed to need improvement, for which specific recommendations were made in the scope of this work. All the details, including the *recommended measures* are given in Appendices I and II, but Chapter 5 has illustrated the whole process with two examples. The referred improvement opportunities had not been identified before with the other methodology currently used in this company (W.T. Fine modified), and this allowed to highlight some benefits of the SFA approach. Among other advantages, this safety analysis approach draws attention of the analyst for factors such as “procedures” and “management/organization” functions.

With regard to the new version of the SFA, the most important innovations, perceived by the team users as very useful, are the new criterion of “monitoring” and the inclusion of the “decision rules”, which guide the analysts towards the acceptance level.

# 7. Conclusions

The SFA (Safety Function Analysis) was first developed from 2000 by Harms-Ringdahl (2001, 2003a, 2003b), as a more specific method for risk evaluation using the concept of *safety function* (SF) as an element for analysis. Later, in 2011, he improved the method by adding new features/characteristics and modifying others, creating a new draft version, which was applied in this work.

The objective of this work was to make a *safety analysis* of a production line of a paper manufacturer. This production line consists of several different processes, of which the author chose two of them to be analyzed in more detail; on the other hand, the two case-studies presented here have helped to understand the new features/characteristics incorporated in the updated version of SFA.

In the first process analyzed (*raw material loading*), 47 safety functions were identified and evaluated, corresponding to two different hazards present in four equipments/infra-structures; of these, 31 SF are related to "*mechanical handling of loads*" and the other 16 to "*fire, electricity, projection of particles and paper dust*". An important aspect is that a significant number of these safety functions (21 out of 47) are associated with human-factors: either procedures or organizational issues. Most of these SFs (32) are working properly and only need to maintain their present condition, whereas others (13) need essential improvement; there were particular cases (2) for which improvement would be beneficial, but it was considered impracticable for technical reasons. As a consequence of the analysis, specific recommendations are proposed in Appendix I; being a manufacturer of paper goods, one of the most important recommendations is perhaps the implementation of thermo graphic tests to identify possible hot spots that may originate a fire.

As for the second process (*transversal cut of log*), 36 safety functions were identified, which correspond to four different hazards present in three equipments/infra-structures; of these 36 SFs, 13 are related to "*contact with sharp elements*", 9 to "*fire*", 8 to "*mechanical contact*" and 6 to "*particles and dust exposure*". Once again, the number of SF in good condition and working properly were the majority (22) against others (14) for which improvement "can be considered" or is necessary (essential). Of the recommendations made (Appendix II), the thermo graphic tests are also considered an important issue. A distinctive aspect in this second case-study was the identification of an “absent” SF that needs to be designed and implemented; the suggestion is to consider a physical barrier to prevent walking through/over the trim conveyor belt, or, if feasible, to create a crosswalk bridge over it.

By applying the SFA method in a real working context, one gains insight of its abilities and limitations.

Some of the ***limitations*** are:

- like many other methods, its application requires good knowledge of the process and the applicable safety functions,

- it is relatively time consuming and, therefore, it is better suited to evaluate only the most relevant issues; it needs a previous assessment, made by other methods, to identify the most important hazards.

Some ***advantages*** are, for instance:

- the methodology is useful to make specific proposals for safety improvements, by identifying problematic, inefficient and missing SFs;

- the SFA is more “safety-oriented” than traditional “risk assessment” methods, which allows to go deeper and do a more comprehensive analysis than other methods do; in addition, it drives the analyst to search for non-technical functions such as, “procedures” and “organizational”;

- it evaluates “safety” rather than potential “risk”, bringing a new point of view to the analysis of the system;

The new 2011 version has some new features, of which two seem particularly useful:

- it considers the “monitoring status” in the evaluation step; this is perceived as useful because a given SF may be accepted as good, but it can also degrade easily if not adequately monitored; monitoring is a way to warrant that “good” stays “good”;

- the table with the decision rules, which provide guidance on the acceptability.

Finally, the new version also provides guidance for an overall evaluation (qualitative) of the entire system. However, this ability was not tested in this study due to time constraints.

# References

Aven, T. (2009). Perspectives on risk in a decision-making context – Review and discussion. *Safety Science*; 47 (2009) pp. 798-806

Carracinha, F. and Jacinto, C. (2009). Application of SFA method to an electrical power sub-station at the company RENOVA (*in Portuguese*). In: Riscos Industriais e Emergentes, C. Guedes Soares, C. Jacinto, A.P. Teixeira, P. Antão (Eds), Edições Salamandra, Lisboa, 2009 (ISBN 978-972-689-233-5), Vol.2, pp. 827-844.

Dujim, Nijs J. (2009). Safety-barrier diagrams as a safety management tool. *Reliability Engineering and System Safety;* 94 (2009) pp. 332-341

EU-Agency (2007). RAT - risk assessment tool. European Union Agency for Safety and health at work, Spain.

Fine, William T. (1971). Mathematical Evaluation for Controlling Hazards. Unclassified NOLTR 71-31; published 8 March 1971. Naval Ordinance Laboratory, White Oak, Maryland

Harms-Ringdahl, L. (2001). *Safety Analysis – Principles and Practice in Occupational Safety*. 2nd Edition. Taylor& Francis, London. ISBN: 0-415-23655-X

Harms-Ringdahl, L. (2003a). Assessing Safety Functions – results from a case study at an industrial workplace. *Safety Science*; 41(8), pp. 701-720.

Harms-Ringdahl, L. (2003b). Investigation of barriers and safety functions related to accidents. Safety & Reliability, Bedford & van Gelder (Eds.), Swets & Zeitlinger B.V., Lisse, Netherlands, Vol. I, pp. 763-768.

Harms-Ringdahl, L. (2004). Relationships between accident investigations, risk analysis, and safety management. *Journal of Hazardous Materials*; 111 pp. 13-19

Harms-Ringdahl, L. (2009). Analysis of safety functions and barriers in accidents. *Safety Science*; 47 (3), pp. 353-363.

Harms-Ringdahl, L. (2011, *unpublished*). Analysis of barriers and safety functions. Chapter 11, draft version, May 2011.

Hollnagel, E. (2004). Barriers and Accident Prevention. Ashgate Publishing Limited, England.

Hollnagel, E. (2008). Risks + barriers = Safety?. *Safety Science*; 46 (2008), pp. 221-229.

Johnson, W.G. (1980). *MORT safety assurance systems*. Marcel Dekker Inc., New York

Kletz, Trevor A. (2001). Hazop and Hazan: Identifying and assessing process industry hazards. 4th Edition, Institution of Chemical Engineers, UK.

Kumamoto, Hiromitsu and Henley, Ernest (1996). Probabilistic Risk Assessment and Management for Engineers and Scientists. 2nd Edition, IEEE Press, USA.

Leveson, N.G., 1995. Safeware. System Safety and Computers. Addison-Wesley, Reading, MA.

Marhavilas, P. K., Koulouriotis, D, Gemeni, V (2011). Risk analysis and assessment methodologies in the work sites: On a review, classification and comparative study of the scientific literature of the period 2000-2009. *Journal of Loss Prevention in the Process Industries*; Volume 24, Issue 5, September 2011, pp. 477-523

OHSAS 18001 (2007). Occupational health and safety management systems – Standard. 2nd Edition, British Standard Institutions, UK.

Sklet S. (2006a). Hydrocarbon releases on oil and gas production platforms: Release scenarios and safety barriers. *Journal of loss prevention in the process industries*; Vol.19, pp. 481-493.

Sklet S. (2006b). Safety barriers; definition, classification, and performance. *Journal of loss prevention in the process industries*; Vol.19, pp. 494-506.

Villemeur, A. (1992). *Reliability, Availability, Maintainability and Safety Assessment*. Vol 1 & 2, John Wiley & Sons, New York.

## Legal references

Decreto-Lei nº 50/2005, de 25 de Fevereiro de 2005, Diário da República, 1ª série – A, nº40, 2005, relativa às prescrições mínimas de segurança e saúde dos trabalhadores na utilização de equipamentos de trabalho (*Decree transposing to the Portuguese law the Directive "use of equipments"*)

Decreto-Lei nº 103/2008, de 24 de Junho de 2008, Diário da República, 1ª série – nº120, 2008, relativo à colocação no mercado e a entrada em serviço das máquinas bem como a colocação no mercado das quase – máquinas (*Decree transposing to the Portuguese law the Directive "machinery"*)

# Appendix I

# Tables with the results of SFA application

***"raw material loading"***

**Table A1 - Safety function evaluation for the process raw material loading (1/2)**

| Equipment or infra-structure | Hazard / Risk | Safety Function | | Intention | Evaluation Process | | | | Code (Recom) |
|---|---|---|---|---|---|---|---|---|---|
| | | Type | Description | | Importance | Efficiency | Monitoring Status | Acceptance level | |
| AGV (load = paper reel; app. 2T) | Mechanical handling of loads | Containement | Cover bars and speed to prevent fall of load | 1 | 2 | 4 | 2 | 0 | 1.1 |
| | • Fall of load | Automatic control | Photoelectric sensors in AGV (proximity of obstacles) | 3 | 2 | 3 | 2 | 0 | 1.2 |
| | • Collision of AGV with person | | Sound and light warnings to indicate the presence/arrival of AGV | 3 | 2 | 3 | 2 | 0 | 1.3 |
| | | Reduction of consequences | First aid team (certified); 24h | 3 | 2 | 3 | 2 | 0 | 1.4 |
| | | | First and Second intervention teams of Renova | 3 | 1 | 4 | 2 | 0 | 1.22 |
| | | Procedures and routines (formal and informal) | Maintenance manual | 2 | 2 | 3 | 2 | 0 | 1.5 |
| | | | Circulation rules to prevent collision with person | 3 | 2 | 3 | 1 | 2 | 1.6 |
| | | Management/Organizational | Equipment verification reports; maintenance policy | 2 | 2 | 3 | 2 | 0 | 1.7 |
| LT1 (lifting truck - spindle) | Mechanical handling of loads | Containement | Solid structure and speed to prevent fall of load | 3 | 2 | 3 | 2 | 0 | 1.1 |
| | • Same as above for AGV | Automatic control | Equipment start-up only with voluntary action | 3 | 3 | 3 | 2 | 1 | 1.8 |
| | | Reduction of consequences | First aid team (certified); 24h | 3 | 2 | 3 | 2 | 0 | 1.4 |
| | | | First and Second intervention teams of Renova | 3 | 1 | 4 | 2 | 0 | 1.22 |
| | (unsafe handling of load) | Procedures and routines (formal and informal) | Maintenance manual | 2 | 2 | 3 | 2 | 0 | 1.5 |
| | | | Circulation rules to prevent collision | 3 | 3 | 2 | 2 | 2 | 1.9 |
| | | | LT1 driver training | 2 | 3 | 4 | 2 | 1 | 1.10 |
| | | | Maintenance operators training in safety | 3 | 3 | 3 | 2 | 1 | 1.11 |
| | | Management/Organizational | Equipment verification reports; maintenance policy | 2 | 2 | 3 | 2 | 0 | 1.7 |
| LT2 (Rolling bridge) | Mechanical handling of loads | Containement | Not applicable; Not identified | - | - | - | - | - | - |
| | • Same as above for LT1; | Automatic control | Control systems clearly identifiable | 2 | 2 | 4 | 2 | 0 | 1.12 |
| | | | Equipment start-up only with voluntary action | 2 | 3 | 3 | 2 | 1 | 1.8 |
| | (unsafe handling of load) | Reduction of consequences | First aid team (certified); 24h | 3 | 2 | 3 | 2 | 0 | 1.4 |
| | | | First and Second intervention teams of Renova | 3 | 1 | 4 | 2 | 0 | 1.22 |
| | | Procedures and routines (formal and informal) | Circulation rules to prevent collision | 3 | 3 | 3 | 2 | 1 | 1.9 |
| | | | LT2 Operator training in safety | 3 | 3 | 4 | 2 | 1 | 1.13 |
| | | | Maintenance operators training in safety | 3 | 3 | 3 | 2 | 1 | 1.11 |
| | | Management/Organizational | Equipment verification reports; maintenance policy | 2 | 2 | 3 | 2 | 0 | 1.7 |
| | Noise exposure<br>• Hearing damage<br>Projection of hydraulic fluid<br>• Eyes damage | Not analized; risk score ≤ 360 | | N/A | | | | | |

**Table A1 (*continued*) - Safety function evaluation for the process raw material loading (2/2)**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| AGV table | Mechanical handling of loads • Fall of load | Containement | Barreirs to prevent access of people when loading | 3 | implementation not practicable; obstructs AGV access | | | | 1.14 |
| | | Automatic control | Safety Switch | 3 | 2 | 3 | 2 | 0 | 1.15 |
| | | Reduction of consequences | First aid team (certified); 24h | 3 | 2 | 3 | 2 | 0 | 1.4 |
| | | | First and Second intervention teams of Renova | 3 | 1 | 4 | 2 | 0 | 1.22 |
| | | Procedures and routines (formal and informal) | Safety signals in danger areas of loading | 3 | 3 | 2 | 2 | 2 | 1.16 |
| | | Management/Organizational | Equipment verification reports; maintenance policy | 2 | 2 | 3 | 2 | 0 | 1.7 |
| | Fire, electricity, projection of particules and paper dust | Containement | Extrating system | 3 | 2 | 3 | 2 | 0 | 1.17 |
| | | | Barreirs for direct contact protection | 3 | 3 | 3 | 2 | 1 | 1.18 |
| | | | Electrical wiring isolation | 3 | 2 | 3 | 2 | 0 | 1.19 |
| | | Automatic control | Smoke detector | 3 | implementation not practicable; very ample space | | | | 1.20 |
| | | | Earth links | 3 | 1 | 4 | 2 | 0 | 1.21 |
| | | Reduction of consequences | First aid team (certified); 24h | 3 | 2 | 3 | 2 | 0 | 1.4 |
| | | | First and Second intervention teams of Renova | 3 | 1 | 4 | 2 | 0 | 1.22 |
| | | | Emergency exits | 3 | 1 | 4 | 2 | 0 | 1.23 |
| | | | Fire extinguishers | 3 | 2 | 4 | 2 | 0 | 1.24 |
| | | Procedures and routines (formal and informal) | Reports analyzing particles of dust for fire prevention | 3 | 3 | 4 | 2 | 1 | 1.25 |
| | | | Thermographic tests | 3 | 2 | 2 | 0 | 3 | 1.26 |
| | | | Periodic cleaning | 2 | 2 | 3 | 2 | 0 | 1.27 |
| | | Management/Organizational | Equipment verification reports; maintenance policy | 2 | 2 | 3 | 2 | 0 | 1.7 |
| | | | Health monitoring | 3 | 2 | 3 | 2 | 0 | 1.28 |
| | | | Periodic evaluation of particles | 3 | 3 | 3 | 2 | 1 | 1.29 |
| | | | Safety reports | 3 | 2 | 3 | 2 | 0 | 1.30 |

**Table A2 - Corrective actions proposed for the process raw material loading (1/3)**

| Code | Requirements of the safety functions | Corrective actions proposed |
|---|---|---|
| **1.1** | The structure (cover bars) of the equipment must be robust to prevent unwanted events as the fall of heavy load; AGV speed must be controlled. | Maintain the current status of functioning and its monitoring. |
| **1.2** | The AGV must have sensors to identify the presence of obstacles or people in order to stop vehicle when necessary. | Maintain the current status of functioning and its monitoring. |
| **1.3** | The AGV must have sound or light warnings to indicate its presence/arrival, so operators can travel safety through the factory. | Maintain the current status of functioning and its monitoring. |
| **1.4** | There must be a first aid certified team ready to act over 24h in the factory. | Maintain the current status of functioning and its monitoring. |
| **1.5** | The AGV maintenance manual must have all the necessary and important information (in Portuguese). | Nothing to improve. The manuals are all in Portuguese and updated. |
| **1.6** | There must be well defined circulation rules to prevent collision with person. | Review and improve the circulation rules and signs in areas where the likelihood of accident is higher. |
| **1.7** | The equipment verification reports must be updated according to any new needs - and the maintenance policy reviewed. | Maintain the current status of functioning and its monitoring. |
| **1.8** | A voluntary action must be applied over a control to start equipments after a stop of any kind, unless the stop results from a normal sequence or an automatic work cycle (legal requirement: Art. 12, DL 50/2005). | Given importance "3" of this SF, an improvement can be considered in order to update the safety switch that starts the equipment (start-up switch) |
| **1.9** | There must be well defined circulation rules to prevent collision with elements. | Improvement of this SF is recommended; in addition, the rules and circulation routes should be reviewed after any changes in the factory layout. |
| **1.10** | On equipments with specific risks, the employer must take special precautions so that the use of that equipment is only made by a qualified operator for the corresponding activity (legal requirement: Art. 5, DL 50/2005). | Maintain the training of drivers updated by revising qualifications every year. |

**Table A2 (*continued*) - Corrective actions proposed for the process raw material loading (2/3)**

| Code | Requirements of the safety functions | Corrective actions proposed |
|---|---|---|
| **1.11** | The employer must also give proper and easy understanding information, to workers and to the safety and health representatives, about the equipment used. That information must have indications of conditions for use of equipment, abnormal predictable situations, acquired experience from the use of equipment and possible due risks (Art. 8, DL 50/2005). | Maintain the training of drivers updated by revising qualifications every year. |
| **1.12** | The Control Systems must be plainly visible, identifiable and, if appropriate, have a proper markup. (Art. 11, DL 50/2005). | Verify if all the controls are in Portuguese. Maintain the current status of functioning and its monitoring. |
| **1.13** | The operator form LT2 machine must have training in safety to meet the safety requirements of LT2 use. | Due to the importance of this SF and this equipment, periodic training in safety can be considered every six months/one year. |
| **1.14** | Barriers to prevent access when loading. | Implementation not practicable; obstructs AGV access. |
| **1.15** | The AGV table must have a safety switch to stop the process when required. | Maintain the current status of functioning and its monitoring. |
| **1.16** | The AGV table must have proper safety signals according to the potential existing hazards. | Improvement is recommended to prevent degrading of signals; different material can be considered. Maintain and verify if the signals are updated and visible; |
| **1.17** | The work equipments must have efficient retention or extraction devices located near the focus point (Art. 15, DL 50/2005). | Maintain the well functioning of the extractors. Monitor their status. |
| **1.18** | The equipment must protect the workers from direct or indirect contact with electricity (Art. 20, DL 50/2005). | Maintain the barriers for protection; however the improvement of barriers can be considered due to its importance. Verify its status periodically. |
| **1.19** | All the active parts of the installation must be completely isolated and must be removed only through destruction. | Maintain the actual isolation and verify its status periodically. |
| **1.20** | Smoke detector. | Not required; Very ample space, smoke easily detected by operators given to their high number in possible areas of fire trigger. |

**Table A2 (*continued*) - Corrective actions proposed for the process raw material loading (3/3)**

| Code | Requirements of the safety functions | Corrective actions proposed |
|---|---|---|
| **1.22** | There must be specific intervention teams for protection and reduction of consequences against fire and electric hazards. | Maintain the teams always ready to intervene. Perform emergency fire exercises. |
| **1.23** | There must be emergency exits well located and properly signalized. | Maintain the current emergency exits, and monitor the status of the signs preventing degradation. |
| **1.24** | Fire extinguishers must be located in accessible places and be appropriate for the nearest kind of hazardous material. | Maintain the fire extinguishers and verify whenever necessary their expiration. |
| **1.25** | The particles of dust must be analyzed for fire protection. | Maintain the frequency of the tests and reports. However, an improvement can be considered. |
| **1.26** | Make thermo-graphic tests in order to identify eventual hot spots that may origin fire start. | It is essential to implement the thermo-graphic tests in the AGV table. Run these tests at least twice a year. |
| **1.27** | The AGV table must be periodically cleaned in order to eliminate the particles of dust accumulation. | Maintain the periodic cleaning once a month; keep records of this activity. |
| **1.28** | Health monitoring | Maintain the good internal occupational medicine (doctors plus nurses). |
| **1.29** | There must be a periodic evaluation of any kind of particles. | Maintain the frequency of the tests and reports. However, an improvement can be considered. |
| **1.30** | Safety reports must be done in order to prevent any kind of health injury. | Maintain the frequency of the tests and reports. However, an improvement can be considered. |

# Appendix II

# Tables with the results of SFA application

## "*transversal cut of log*"

## Table A3 - Safety function evaluation for the process transversal cut of log (1/2)

| Equipment or infra-structure | Hazard / Risk | Safety Function: Type | Safety Function: Description | Intention | Evaluation Process: Importance | Evaluation Process: Efficiency | Evaluation Process: Monitoring | Evaluation Process: Acceptance level | Code (Recom) |
|---|---|---|---|---|---|---|---|---|---|
| Saw cabine | Contact with sharp elements | Containement | Physical barriers preventing access to cutting saw | 3 | 3 | 4 | 2 | 1 | 1.1 |
| | • Pinching, crushing, cutting | | Protection of moving elements | 3 | 3 | 2 | 2 | 2 | 1.2 |
| | | | Accessibility to the cabine | 3 | 3 | 4 | 2 | 1 | 1.3 |
| | | | Use of EPI's when accessing the cabine | 3 | 2 | 4 | 2 | 0 | 1.4 |
| | | Automatic control | Safety Switch | 3 | 2 | 4 | 2 | 0 | 1.5 |
| | | | Equipment start-up only with voluntary action | 3 | 3 | 4 | 2 | 1 | 1.6 |
| | | | Control devices far from dangerous areas | 3 | 2 | 4 | 2 | 0 | 1.7 |
| | | Reduction of consequences | First aid team (certified); 24h | 3 | 2 | 3 | 2 | 0 | 1.8 |
| | | | First and Second intervention teams of Renova | 3 | 1 | 4 | 2 | 0 | 1.9 |
| | | Procedures and routines (formal and informal) | Periodic preventive maintenace | 2 | 2 | 3 | 2 | 0 | 1.10 |
| | | | Safety signals informing the presence of cutting element | 3 | 2 | 2 | 2 | 2 | 1.11 |
| | | | Maintenance operators training in safety | 3 | 3 | 3 | 2 | 1 | 1.12 |
| | | Management/Organizational | Equipment verification reports; maintenance policy | 2 | 2 | 3 | 2 | 0 | 1.13 |
| | Material accumulation, paper dust | Containement | Extracting system | 3 | 3 | 2 | 2 | 2 | 1.14 |
| | | | Electrical wiring isolation | 3 | 2 | 3 | 2 | 0 | 1.15 |
| | • Fire | Automatic control | Smoke detectors | 3 | 3 | 2 | 2 | 2 | 1.16 |
| | | Reduction of consequences | First aid team (certified); 24h | 3 | 2 | 3 | 2 | 0 | 1.8 |
| | | | First and Second intervention teams of Renova | 3 | 1 | 4 | 2 | 0 | 1.9 |
| | | Procedures and routines (formal and informal) | Reports analyzing particles of dust for fire prevention | 3 | 3 | 4 | 2 | 1 | 1.17 |
| | | | Thermographic tests | 3 | 2 | 2 | 0 | 3 | 1.18 |
| | | | Periodic cleaning | 2 | 2 | 3 | 2 | 0 | 1.19 |
| | | Management/Organizational | Equipment verification reports; maintenance policy | 2 | 2 | 3 | 2 | 0 | 1.13 |
| Trim Conveyor Belt | Mechanical contact | Containement | Barriers preventing walkthrough over the trim conveyor | 3 | 2 | 0 | 0 | 3 | 1.20 |
| | • Pinching, crushing, cutting | | Protection of moving elements | 3 | 3 | 2 | 2 | 2 | 1.2 |
| | | Automatic control | Equipment start-up only with voluntary action | 3 | 3 | 3 | 2 | 1 | 1.6 |
| | | | Safety Switch | 3 | 2 | 3 | 2 | 0 | 1.5 |
| | | Reduction of consequences | First aid team (certified); 24h | 3 | 2 | 3 | 2 | 0 | 1.8 |
| | | | First and Second intervention teams of Renova | 3 | 1 | 4 | 2 | 0 | 1.9 |
| | | Procedures and routines (formal and informal) | Periodic preventive maintenace | 2 | 2 | 4 | 2 | 0 | 1.10 |
| | | Management/Organizational | Equipment verification reports; maintenance policy | 2 | 2 | 3 | 2 | 0 | 1.13 |
| Conveyor exiting the saw | Removal of product; line in motion • Pinching, crushing, cutting | Not analized; risk score ≤360 | | N/A | | | | | |

**Table A3 (*continued*) - Safety function evaluation for the process transversal cut of log (2/2)**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Dust Removal system | Particles and dust exposure | Containement | Solid structure to prevent leaks from silo | 3 | 2 | 3 | 2 | 0 | 1.21 |
| | • Respiratory irritation | Automatic control | Equipment allw ays active | 2 | 3 | 3 | 2 | 1 | 1.22 |
| | • Eye damage | Reduction of consequences | First aid team (certified); 24h | 3 | 2 | 3 | 2 | 0 | 1.8 |
| | | | First and Second intervention teams of Renova | 3 | 1 | 4 | 2 | 0 | 1.9 |
| | | Procedures and routines (formal and informal) | Periodic cleaning | 2 | 2 | 3 | 2 | 0 | 1.23 |
| | | Management/Organizational | Equipment verification reports; maintenance policy | 2 | 2 | 3 | 2 | 0 | 1.13 |

**Table A4 - Corrective actions proposed for the process transversal cut of log (1/3)**

| Code | Requirements of the safety functions | Corrective actions proposed |
|---|---|---|
| **1.1** | There must be physical barriers to prevent an easy access to the saw. | Due to the importance of this SF, the physical barriers can be improved with higher resistance material. |
| **1.2** | The moving elements liable of causing accidents by mechanical contact must have protecting devices with robustness that stop the access to dangerous areas, or devices that interpose the movement of elements before they access those areas. (Art. 16, DL 20/2005) | Improvement is recommended to prevent degrading of SF; However, maintain the current status of functioning and its monitoring. |
| **1.3** | The accessibility to the cabin must be of difficult access. | A new system to access the cabin can be considered. |
| **1.4** | When accessing the cabin, operators must use EPI's for protection. | Maintain and verify the good status of the referred EPI's; Maintain the signs about their proper use; Monitor is essential. |
| **1.5** | There must be a safety switch to stop the process whenever required. | Maintain the current status of functioning and its monitoring. |
| **1.6** | A voluntary action must be applied over a control to start the equipments after a stop of any kind, unless the stop results of a normal sequence or an automatic work cycle (Art. 12, DL 20/2005). | Given the importance of this SF, an improvement can be considered in order to update the safety switch that starts the equipment (start-up switch) |
| **1.7** | The control devices must be far from the access to the cabin or any dangerous areas. | Maintain the current status of functioning and its monitoring. |
| **1.8** | There must be a first aid certified team ready to act over 24h in the factory. | Maintain the current status of functioning and its monitoring. |
| **1.9** | There must be specific intervention teams for protection and reduction of consequences against fire and electric hazards. | Maintain the teams always ready to intervene. Perform emergency exercises. |
| **1.10** | There must be done preventive maintenance in the saw cabin, at least periodically in order to maintain the good status of the saw. | Maintain the current status of functioning and its monitoring. |
| **1.11** | The saw cabin must have proper safety signals according to the potential existing hazards. | Maintain and verify if the signals are updated and visible; Monitor is necessary, at least periodically; prevent degrading of safety function. |

**Table A4 (*continued*)- Corrective actions proposed for the process transversal cut of log (2/3)**

| Code | Requirements of the safety functions | Corrective actions proposed |
|---|---|---|
| **1.12** | The employer must also give proper and easy understanding information, to workers and to the safety and health representatives, about the equipment used. That information must have indications of conditions for use of equipment, abnormal predictable situations, acquired experience from the use of equipment and possible due risks (Art. 8, DL 50/2005). | Maintain the training of operators in safety updated. Any improvements regarding safety can be considered and instructed to the operators. |
| **1.13** | The equipment verification reports must be updated according to any new needs - and the maintenance policy reviewed. | Maintain the current status of functioning and its monitoring. |
| **1.14** | Work equipments must have efficient retention or extraction devices located near the focus point (Art. 15, DL 50/2005). | Improvement of extractors is recommended, despite their reasonably good condition; Monitoring is essential and should not downgrade. |
| **1.15** | All the (electrical) active parts of the installation must be completely isolated; their removal should only be possible through destruction. | Maintain the current status of functioning and its monitoring. |
| **1.16** | The warning devices (from smoke detectors) must be clearly heard and easily understood without ambiguity (Art. 18, DL 50/2005). The saw cabin must have a smoke detector inside. | Improvement is recommended. |
| **1.17** | The particles of dust and their concentration in the air must be analyzed periodically (for fire protection). | Maintain the frequency of the tests and reports. However, an improvement can be considered. This needs to be discussed with management to find out the best cost-benefit solution. |
| **1.18** | Make thermo-graphic tests in order to identify possible hot spots that may originate fire (source). | It is essential to implement the thermo-graphic tests in the cabin saw. Run these tests at least twice a year. |
| **1.19** | The saw cabin must be periodically cleaned in order to eliminate dust accumulation. | Maintain the periodic cleaning once a month; keep records of this activity. |

**Table A4 (*continued*)- Corrective actions proposed for the process transversal cut of log (3/3)**

| Code | Requirements of the safety functions | Corrective actions proposed |
|---|---|---|
| **1.20** | The moving elements liable of causing accidents by mechanical contact must have protecting devices with robustness that stop the access to dangerous areas, or devices that interpose the movement of elements before they access those areas. They must be situated in a secure distance and must not limit the work cycle observation (Art. 16, DL 50/2005). | Improvement is essential.<br>It is essential to create a physical barrier to prevent walking through (or over) the trim conveyor belt, or, if feasible, create a crosswalk bridge over the conveyor. |
| **1.21** | The dust removal system (main extraction system) must have a solid structure in order to prevent any leak. | Maintain the current status of functioning and its monitoring. |
| **1.22** | The dust removal system must always be active, regarding any paper transformation process. | Maintain and monitor periodically the current status of the dust removal system. This SF can be improved since functioning is essential to mitigate the air contamination with paper dust particles. |
| **1.23** | The dust removal system must be cleaned in order to prevent the obstruction of the system. | Maintain and monitor periodically the current status of function and its monitoring. |