Identifying and Responding to Weak Signals to Improve Learning from Experiences in High-Risk Industry

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Identifying and Responding to Weak Signals to Improve Learning from Experiences in High-Risk Industry

Proefschrift

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To my father.

Contents

PART 1: BUILDING THE RESEARCH QUESTION

Introduction

1.1 Context of the PhD research

This thesis is part of a research program funded by FonCSI (Fondation pour une Culture de Sécurité Industrielle). The objective of FonCSI is to facilitate improvements in terms of safety in risky industries. To do so, the foundation is working on making bridges between research teams, industrial partners and all other stakeholders, and in funding research programs on the issue of safety.

Between 2004 and 2005, FonCSI launched a working group composed of representatives from French industry on the subject of what is known in France as Retour d'Expériences (Rex). This can best be translated into English as "Learning from Experiences", though there are distinctly French flavours to the phrase and the way in which it is interpreted in France, so the term Rex is used throughout this thesis. This working group met a dozen times, allowing participants to present and compare best practices, problems and gaps between practices and objectives. Discussions in the group highlighted the diversity of different companies' practices in the management of Rex. While the companies participating considered that the technical aspects of the problem (use of database tools to aid incident reporting, analysis of the technical origin of incidents) were well managed, some common themes were identified as causing problems, reflecting a need for research in this field.

The FonCSI launched a Call for Proposals in 2005 entitled "Sociocultural Success Factors for Learning from experiences (Rex): Seven Field Studies". The aim of the research program is to produce knowledge about the function and role of Rex and to identify best practices in the field of Learning from experiences (Rex). FonCSI selected and funded seven PhD theses, each of them involving a significant amount of fieldwork in different industrial sectors. Industrial companies from different fields of activity opened some of their sites to the researchers:

- Energy and metallurgy
- Chemicals, petrochemicals and pharmacy
- Transport

The seven PhD projects dealt with:

-Socio-cognitive biases and their potential for interference with Learning from experiences (Rex) among workers from two nuclear and two chemical plants

-Safety assumptions and evolution of safety models in aviation (aircraft design and manufacturing, airline operations, maintenance operations and air traffic management),

-Integration of weak signals in the health and safety management system of a pharmaceutical company,

-Decision-support dimension of operational Learning from experiences in risk management, including the design of a decision support system for managers in rail transportation,

-Identification and implementation of good practices for operational Learning from experiences in the rail industry,

-Inter-organizational learning in aircraft co-design projects

The project which forms the basis of this thesis was the seventh PhD, which was defined by the research team before my appointment as a study of the question of weak signals in Rex, their nature and role in learning.

This thesis was supported by a project team composed of two experts of INERIS (Institut National de l'Environnement Industriel et des Risques) and one expert of the department of Research and Development of EDF (Electricité de France). This team, in discussion with FonCSI considered that there was a lack of detailed study (particularly in sociology) to explore the construction of the signals to initiate learning, as well as a lack of a clear theoretical formulation of "weak signals", which led to the necessity to discuss the issue of weak signals in both scientific and practical terms.

1.2 The scope of the PhD research

Weak signals are forging an ever more visible place in research in the scientific community and high-risk industry. Studies on this subject have now laid the groundwork for a generic definition, and describe weak signals as signs warning of a financial, psycho-social or technological risk, that are difficult to detect. The investigative report led by the British Petroleum about the accident at the Deepwater Horizon platform which occurred on April 22, 2010, "*identifies eight points which, combined, have led to the explosion, and emphasizes a crucial period of "forty minutes" before the explosion, during which "the Transocean team did not detect and react to the influx of hydrocarbons into the well until the hydrocarbons go back to the surface quickly, causing gas evolution and explosion*" (article taken from *Libération*, September 9, 2010). The remarks of the President of France Telecom-Orange company "*We have not sufficiently taken into account the weak signals which were present*," in response to many suicides that occurred in this global telecommunications group in 2008 and 2009, amplify in turn the visibility of weak signals in the media and anchor them in the reality of the news.

These two examples illustrate the main problem of weak signals. Visible in retrospect, but not seen in prospect, they could have pushed actors of an organization to the awareness of an impending catastrophe, but confirm now their inability to act. Predictors but imperceptible, such is the ambivalence of weak signals.

1.3. What do we learn from accidents?

Accident analysis, in which Turner (1978) and Vaughan (1996) are two pioneering figures, has led to the two following conclusions to the question "what we learn from accidents". First, a series of studies have addressed the issue of warning signs of accidents. According to Llory (1999), an accident "*does not come out of nothing*," it is the result of a multitude of events that have accumulated over a long period, the "incubation period" (Turner, 1978). This period then reveals the slow formation of an unfavourable terrain in terms of safety, which is manifested by the emergence of warning signs, often undetected. Diving into the history of the Challenger shuttle accident (Vaughan op.cit.) indicates that thirteen years before this tragedy NASA had decided to develop the boosters which failed, despite acknowledging the technical shortcomings of the sealing system, which was the proximate cause of disaster. Weak signals seem promising as an issue in terms of risk prevention. Often recurring – such as the defects in closing the baggage compartment of the Turkish Airlines plane before the crash at Ermenonville - weak signals indicate the persistence of certain dysfunctions of safety, enabling us to think of the possibility of preventing an accident (Llory, 1996).

Second, other studies describe accidents as complex phenomena whose causes often go beyond only the technical and behavioural dimensions. They see accidents as revealing organizational "pathogens" causing an event. Turner & Pidgeon (1997), among others, identified two factors: faulty communication and transmission of information related to safety, due to the proliferation and complexity of social relations within an organization, and a difficulty to consider or perceive risk. These factors contribute to blindness and impede an organization to amplify or give sense to warning signs of accidents. The message conveyed by these signals is weakened and filtered out by the organization, based on beliefs about technological and managerial expertise and hindered by the management of increasingly complex technology and communications.

Accident analysis teaches us that an accident is not (only) seen as the result of one or more technical failures but should be defined in sociological terms (Pidgeon and O'Leary, 2000) as "a significant disruption of cultural norms and beliefs about existing risks and ways to control them" (Dien, 2006).

1.4 A proactive safety management

In the face of these remarks, requirements in terms of safety management become harder. Although Amalberti (2001) refers to certain systems as "ultra-safe", that is to say that those organizations may have already reached more than satisfactorily high levels of safety, the challenge for these organizations to progress further is now formidable. It is indeed to meet the requirements of proactive prevention of accidents, requiring a significant innovation of risk controls to put in place at industrial sites.

The European Seveso 2 Directive (issued December 9, 1996 and amended in 2003) is translated in France as a law on the prevention of major accidents at industrial sites, requiring upper level Seveso sites, among other things, to implement a Safety Management System (Text of Annex III of the decree of May 2000 on the prevention of major accidents). 'Learning from experiences'[1] , or Retour d'Expériences (Rex) in French is put forward, in this decree, as a main tool of the safety management system (SMS). It allows sites to trace anomalies and significant events occurring at an industrial site, to find the causes and implement corrective and preventive actions to address the problems identified in order to avoid their repetition. Rex should have two objectives. It should provide an element of proactive safety management by identifying potential weak signals of an accident, and hence contribute to the organizational reliability of the site. The work of the Berkeley group, whose main object is the study of High Reliability Organizations or HROs (Weick 1997, La Porte 1996 and 1999, Roberts 1989), emphasizes in this respect that an organization is highly reliable when it has succeeded in developing a particular attention or vigilance to observe weak signals and to develop ways to respond to them (Weick, Sutcliffee & Wiley 2001). Secondly, Rex is a preferred vehicle for taking into account large and complex multi-causal accidents, by generating deep learning factors implicated in an accident sequence.

The ability to detect and respond to weak signals would then consolidate or improve the practices of Rex. If identified early and included in the process of feedback, attention to weak signals may allow organizations to identify upstream repetitive failures that could degrade safety, and identify organizational pathogens as factors involved in an accident sequence.

[1] This term, in French 'Retour d'expériences' or Rex, has no satisfactory English translation. We use in this thesis the literal translation 'Learning of experience', but this may have too limited a connotation. Rex is used in French to cover the whole process of recording of accidents and incidents, their analysis and the use of the analysis for learning. In the rest of the thesis we will therefore use the French abbreviation Rex, since the work conducted here was undertaken in a French context.

1.5 Limitations of “Retour d’Expériences”

Despite its application and almost routine use, Rex may have three main limitations according to previous research. Firstly it is often only reactive (Gilbert 1999; Bourrier 2001, Dien & Dechy 2007) insofar as it is not systematically mobilized before an accident happens, but only once a significant event has occurred, which severely limits taking into account the weak signals of an accident, which are thus only seen with the perfect vision of hindsight. Secondly, lessons learned are currently mainly oriented towards technical aspects, that is to say that the integration of human and organizational factors is still only in its infancy. Finally, Rex tends to be confused with the establishment of a database, without any real prior reflection on data analysis having been conducted (Gilbert & Bourdeaux, 1999). In that case the organization can only reach a first level of organizational learning (Svedung & Radbö, 2006), that is to say that the lessons learned from accident analysis would only concern remedial revision of risk control practices (such as behaviour, respect of rules) and revision of the effectiveness of procedures. According to the studies quoted above, Rex is currently often a failure and, difficulties remain. Weak signals, being barely perceptible, are filtered out. They reveal themselves most often only after the event because, at the time of the accident analysis, the link between the weak signals and the accident sequence becomes manifest.

While continuing to hope that, in time, attention to weak signals will resolve the current limitations in Rex and pave the way for a more proactive safety management, both academics and industries face the same obstacles; if weak signals remain relatively imperceptible, in theoretical and practical terms, can we assume their existence? Are weak signals an intellectual trap, embodying the belief that accidents are predictable, or do they constitute a new challenge to anticipate risks and crisis situations for high-risk organizations ? By studying in depth how Rex worked in two different companies, of different industries, it was hoped to collect rich evidence relating to these questions, which would give more of a basis for hypothesis formation and developing understanding of why Rex might or might not work. In this way, the study was designed to go beyond the confines of case studies and contribute to the development of theory. At the same time it was hoped that the insight given to the companies themselves about the working of their Rex systems would assist them in improving their learning

1.6 Theoretical framework and methodology: research hypotheses

In order to answer these questions, we chose to question the issue of weak signals by using the approach of action research. It offers a dual perspective. First, it allows, in a first stage, an occasion for carrying out a sociological diagnosis on two organizations to define operational weak signals, those feeding learning processes such as Rex, and to question the relevance of “weak signals” as an object of research. Do weak signals have an existence or do they more reveal organizational functioning of learning systems (such as Rex) and factors that block the treatment of such signals? Second, it offers, in a second stage, an occasion for questioning the operationalisation of weak signals. Do they provide relevant data for designing actions that would allow the formulation of recommendations designed for companies running high-risky activities?

For the diagnostic part, we have chosen to address the issue of weak signals in terms of the sociology of organizations. Two case studies were carried out: the first one on a petrochemical site, EDIA, and the second one on a steel plant, ACIO[2]. We have used two approaches. On the one hand, we have analyzed several accidents occurring on each site - one accident at EDIA and three at ACIO - to understand how Rex is implemented and operated and to what extent the issue of weak signals is addressed and taken into account. Secondly, we have studied the normal functioning of the Safety Management System (i.e. activities to ensure safety outside of any accidental event) to highlight technical and organizational arrangements aimed at capturing weak signals before the event, and to identify organizational factors blocking and/or amplifying weak signals. We chose to focus the data collected primarily on the operational levels in the companies, because we believe that the relevant information that could be processed to foresee accidents, emerges from the ground, that is to say from the activity (refining and steel making) of each site. Based on these data we collected some information about how the signals were treated at higher levels of management, but there was not time to sample these levels in detail. Hence, the conclusions about the effectiveness of those levels are based largely on what emerged from them to influence and change operational actions. To conduct these case studies, we followed a qualitative and empirical methodology by carrying out a series of interviews, observations and studies of the internal documentation. Relying on the approach of "grounded theory" (Strauss & Corbin, 1998), which induces results from the linking and analysis of empirical data collected in the field, we conducted a study to redefine weak signals, which is presented in this thesis. The hypotheses for this study are summarized briefly here, but will be more fully derived from the literature chapter.

First hypothesis. We propose that weak signals are fragmented and complex information, which are the manifestation of deeper degradations of safety. They are characterized by their relative invisibility, and are, in that respect, a real theoretical and practical challenge.

Second hypothesis. We hypothesize that the main difficulty is not in the detection but in the treatment of weak signals. Mostly now only identified after the event, we want to identify

[2] These are invented names to honour the anonymity of the companies concerned.

organizational factors that prevent the two sites investigated ’making sense’ of weak signals before an accident occurs, and the factors that maintain conditions in a favourable state for the persistence of those blocking factors.

Third hypothesis. We hypothesize also that these factors blocking the treatment of weak signals mean that the two organizations are not grasping sufficiently the opportunity to learn about the organizational dysfunctions that weak signals might reveal. We expect that their event analyses will be limited to technical and procedural dimensions. They will limit their actions to correcting the anomalies and significant events detected, without questioning their organizational or Rex practices. This will keep EDIA and ACIO in an organizational single loop learning mode.

For the action part, on the basis of the sociological diagnosis, we wanted to offer recommendations to both sites to address the issues raised. The method of risk control developed by Hale & Guldenmund (2004) gave us the opportunity to put our results in terms of the founding principles of this method.

Fourth hypothesis. We hypothesize that the organizational failures that we have identified and defined as the root of the difficulty of handling weak signals can be partly answered by putting the so-called Delft model into operation.

1.7 Thesis structure

This thesis is composed of three parts. The first part, devoted to the construction of the research question, includes the introduction, literature review (chapter 2) and the methodology (chapter 3). Chapter 2 aims to place the concept of weak signals in the historical context of how safety management works, and to discuss the different research areas that have studied weak signals, both in their theoretical and practice perspectives. Chapter 3 discusses the methodological aspect of the work. To meet the challenges of weak signals, we will present in detail the various stages of action research and data collection, the negotiation and duration of periods of fieldwork, the nature of the data, the analysis phase resulting in formalizing and comparing results. Action research appeared relevant because the sociological diagnosis allows us on the one hand to define weak signals and identify the issues they raise and, on the other hand, on the basis of the data analyzed and compared, to set up actions to solve, at least partially, the issue of their treatment.

The second part of this thesis presents the results arising from the case study at EDIA (Chapter 4) and at ACIO (Chapter 5). For each, we present the processes carried out and managed on the site, the results from the accidents analyses we carried out, and the results from the analysis of the normal functioning. These results will be used to test the first three research hypotheses.

The third part consists of the synthesis of the results (Chapter 6) and the final conclusion (chapter 7). Firstly, we will focus on comparing the results from the two case studies, by identifying three categories of weak signals common to both sites: technical weak signals, weak signals related to professional coordination, and weak signals related to the underestimation of risk. Secondly, we will identify three organizational blockers at the origin of the formation and persistence of these signals: organizational fragmentation, safety management fragmentation and a process of information filtering. Then, relying on the sociological diagnosis and the Delft model (Hale & Guldenmund, 2004), a section will be devoted to recommendations which will be designed as a help for both sites to recognize and respond to weak signals, through targeted actions of safety management. This addresses the fourth hypothesis. Finally, we will offer the reader an evaluation of action research, addressing more specifically the contributions but also the limitations of this method in the context of our research. Finally (chapter 6) summarizes the conclusions from the research.

The objectives of the thesis are twofold. On the one hand, the issue of weak signals will provide theoretical inputs on the issue of learning systems and particularly the organizational factors which may block the recognition and treatment of information such as weak signals. In this perspective, we assume that weak signals are not intrinsically weak but are weakened in context. On the other hand, we would like to provide some ideas for action to overcome the difficulties of handling weak signals which we have raised. This research is based on only two case studies, and therefore the results need to be considered as, hopefully well-founded, hypotheses that should be further tested in other companies. That will constitute a basis and proposal for continuing research.

2. Literature review

2.1 Introduction

2.1.1 The start of the project

At its start, this PhD project (as specified in the project description developed in collaboration with FonCSI by the research team) required the combination between three competences: knowledge on learning organizations (learning facilitated by the detection and treatment of weak signals), knowledge on a specific domain of application, major hazard prevention in complex, technical organizations, and competences in the sociology of organizations and especially the capacity of observing and understanding empirically how organizations work.

My background is purely in sociology. Through my studies I found an intellectual interest in a specific "school" in which Anselm Strauss and Everett Hughes[3] are leading and representative figures. They applied "symbolic interactionism" for understanding organizations. I continued my studies in a professional Masters, in which I became strongly interested in applying sociology to organizations. I learnt the job of consultancy with a sociological approach (in which M. Uhalde was a very important mentor, himself part of Sainsaulieu[4]'s "school"). This professional practice has three components. First, it puts the emphasis on sociological diagnosis, that is to say on the importance of observing and understanding how organizations work. For this, a qualitative methodology is appropriate which requires time and investment for conducting a good diagnosis. Secondly, this practice implies a willingness to change, or, at least, to help organizations to be aware of problems that the sociological diagnosis may reveal. Thirdly, this practice is not based on models (an engineering approach), but on an empirical approach, close to Grounded Theory.

I came to Safety Science Group with this knowledge, background and experience, which led to two difficulties. On the one hand, I had to immerse myself in a new set of literature, dealing with safety science and learning organizations, and to give up, for a time, sociology. The fruits of this immersion and its (re)connection to sociology are to be found in the literature review and the rest of the thesis. On the other hand, my supervisors had a different background and a different way to "search" than mine, and it took time to understand each other. For many PhD students, starting a PhD research means "entering" a research laboratory and "carrying on" its work, which may often include applying the research work previously conducted by the supervisors. However, my

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[3] Hughes E., (1971), *The sociological eye*, Transaction publishers, third edition, United States of America.
Strauss A., (1978), *Negotiations: varieties, processes, contexts, and social order*, Jossey-Bass, United States of America.

[4] Sainsaulieu R., (1987), *Sociologie de l'organisation et de l'entreprise*, Presses FNSP-Dalloz, Paris.

perception and practice of research were too different in this instance to fit in easily with the approaches and models developed in the Safety Science Group in Delft. However, I strongly believed that my background in sociology was relevant and worthwhile, and that its empirical approach could provide new insights into the issue of weak signals. Hence, I rejected the idea of applying a preconceived model to the fieldwork and insisted that I would first observe and describe the organizations in which I would carry out my case studies. Fortunately my supervisors gave me the freedom to do this and trusted me, although they might have had doubts about my methodology, which is more deductive than hypothetico-deductive. The first results came relatively late (I carried out my case studies in the second and third year of my PhD research) mainly because qualitative methodology requires time to write down notes and treat data, which did not reassure my supervisors. Nevertheless, they agreed that the preliminary results (derived from both case studies) proved that my approach was justified in the context of this research. As mentioned in chapter one, empirical research on weak signals was, from my point of view and from studying the previous research, missing, and I considered that it was necessary to complement theoretical work with empirical data. In these initial periods of data collection I did not raise the question of “how weak signals could improve learning systems such as Rex” but “what are weak signals and what makes them weak in different, very specific organizational contexts?”.

After this stage, as I turned to making sense of the data and its practical relevance, I also understood (and finally admitted!) the relevance of using the model developed by Andrew Hale and his research model (presented in chapter 2). It helped me to frame my ideas and hypotheses, and particularly to “rate” the learning maturity of both case studies.

2.1.2. The scope of literature review

This research addresses several items - weak signals, Learning from experience (or Rex, see section 1.1) and organizational learning, for which it is necessary to provide a definition and an articulation. The line of argument and the difficulties of conducting such multidisciplinary research are set out in the next paragraphs and then developed in the rest of the literature review.

This research aims to understand how organizational learning can maintain or even improve the reliability of organizations managing a high-risk activity - chemical, nuclear, aviation. Within these organizations, Rex is meant to identify and analyze critical events, and to implement practical measures to reduce the occurrences of critical events. In this sense, Rex is promoted as one of the main tool of safety management in these industries. Many authors but also industrialists point out limits to this approach. The practices of such Rex are mostly "reactive" and often draw lessons limited to the technical dimension of accidents. Formalized learning through Rex does not seem to guarantee substantive learning. This finding has generated a debate on the application of innovative tools for overcoming the failures of such Rex and developing a more proactive management of risks. Weak signals, information alerting to a potential threat to safety, then pave a new path in safety management. Identified upstream of events, they would break the accident sequence and/or minimize its consequences, ultimately reducing the recurrence of critical events. Weak signals would thus have two virtues: a potential to anticipate accidents and a potential to aid learning for organizations managing a risky activity.

This literature review aims to discuss major theoretical trends that have enabled me to build my research question. I have, throughout this project, attempted to find a compromise between my initial training in sociology, concerned with the description and analysis of social dynamics in organizations, and the literature on safety management more oriented towards engineering and committed to developing models for solving problems. The originality of this work, as discussed in section 2.1.1, lies in the effort I have put in to develop a sociological diagnosis and link it to a practical method of application. The large gap between these two was nevertheless difficult to bridge, as each discipline has different tools, skills and theoretical fields and this research on weak signals is still perhaps halfway between a sociological analysis of the issue of weak signals and finding a method to solve - at least partially - the question of weak signals treatment. My purpose was not to supplant the management sciences with a descriptive sociological analysis. It was rather to find a balance and complementarity between the need and importance to describe, understand and analyze the social dynamics of an organization, and to propose a method of solving the problem. The balance between these two dimensions may not be easy, but striving to reach this compromise may be an improvement for a sociological analysis, which focuses very infrequently on the requirement of practical solutions in organizations, but also for management sciences.

This literature review was designed as follows. Each section develops a dimension or pillar of the definition of weak signals. Each of them is articulated in such a way as to add up to a final definition at the end of chapter. This definition allows the specification of the various objects that constitute the research work, namely the analysis of accidents, the management of risk in organizations with high risk and organizational learning.

This chapter is composed of three parts. After recalling the basic concepts constituting the context of this research - the concepts of reliability, complex organizations and systems – section 2.2 will deal with the analysis of events. This shows that an accident has a preparatory, or incubation period, during which warning signs emerge, but whose interpretation is often difficult. The analysis of accidents as a way of revealing weak signals is the first pillar of the definition of weak signals.

Central to the analysis of accidents is Rex. Defined as accident and incident analysis implemented on industrial sites that manage high-risk activities, Rex has two objectives: reducing the occurrence of accidents and promoting a dynamic organizational learning. I address three main limitations to this approach: analysis of critical events are often limited to the technical dimension, provide a limited organizational learning, and, despite more proactive management practices, have difficulties to take account of the issue of weak signals. Feedback as an attempt to integrate weak signals in the analysis of events constitutes the second pillar of my definition.

To address these limitations, section 2.3 will deal with two approaches. Firstly, we will discuss a series of works on organizational learning, including the Organizational Learning System (Koornneef, 2000).The interest of this work lies in three elements. First, these studies show that organizational learning can drive a proactive safety management that enables organizations to position themselves ahead of the critical events and to identify, categorize and process weak signals predicting accidents. Organizational learning must nevertheless be organized through the creation of the functions and resources required to implement this learning effectively. The identification and treatment of weak signals through a process of organizational learning form the third pillar of my definition. As a second approach, Hale (1997) proposes a more global approach to risk control. By identifying indicators of deviation of risk controls, the organization may be able to pinpoint the sources of emerging risks, and implement control measures and prevention so that this deviation does not develop into an accident sequence. However, depending on the organizational context in which this approach is considered, it can be difficult to implement it. The implementation of this project may be difficult in an organization characterized by organizational fragmentation, which may weaken the quality of information transmission related to safety, particularly the information with a potential as a safety alert. We conclude that the problem of weak signals reveals a difficulty in processing information.

The third and final section (2.4) will address the issue of weak signals in terms of sense-making and communication theory. The main hypothesis here is that weak signals are information which is not interpreted as a threat to safety. The frameworks of interpretation of information used by organization’s members are not relevant for dealing with weak signals. In order to integrate weak signals into the feedback requires, at both an individual and a collective level, revising these frameworks for understanding the problem of weak signals treatment. In this way, weak signals could become a vehicle of individual and organizational learning.

2.2 Organizations in high-risk complex socio-technical systems

The field of risk has built itself an ever more important place in the academic literature, especially in the field of the social sciences Risk is a very wide domain but I choose here to consider it only from one particular angle, organizations that manage a high risk activity.

2.2.1 Background research

2.2.1.1 Socio-technical systems, reliability and complex organizations: new research issues

My research fits into this specific context: socio-technical and complex systems. As suggested by Lecoze & Lim (2003): "*Mistakes or failures are the result of the operation of a system that must be considered in its entirety*" (p. 13). This perspective therefore needs to acquire a deeper understanding of these complex organizations: what characteristics define them? What is their structure and mode of organization? Are these organizations unique or do they possess the same characteristics as "classic organizations? The next section recalls some characteristics of organizations and attempts to provide answers to the question of the specificity of high risk organizations.

Rasmussen (2000) identifies four major trends that characterize the social context in which high risk organizations operate. He identifies a rapid pace of technological change, an increase in the size of industrial facilities which is associated with a potential growth in the number of accidents and therefore a need to reduce their likelihood, a growth in systems organized in a tightly coupled way and, finally, an increasingly aggressive and competitive environment. This new context characterized by its complexity has become a central issue as it defines or redefines the contours of these high-risk organizations. These technical, organizational and environmental changes generate new needs in terms of risk management, as we shall see later in this chapter.

Other authors have identified developments intrinsic to these organizations. LaPorte (1996) defines high-risk organizations as systems in which an accident would have the following consequences: a challenge to the economic viability of these systems, a significant decrease in their ability to fulfil their public mission, significant damage to the workforce and residents, and finally a burden on the environment. These are organizations where we are afraid of the potential for extensive damage but at the same time are less and less willing to tolerate errors. Because of the potential damage that an accident could cause, these organizations are watched closely by both the legal authorities (inspection of classified installations in France for example) but also by residents' associations (and any other stakeholder). They are also often characterized by complexity, both technical (Perrow, 1984) due to the technology used by their activity, but also organizational. Finally, they are characterized by their systemic organization which implies that each component element “*material or not, depends reciprocally on each other to form an organized whole* "(Ferréol, 2002). High-risk organizations are considered in this research as complex organizations, operating systems where the technology, the people, the organizational structure and the environment are inextricably linked.

2.2.1.2. The third era of work on safety management

This new social context of high risk organizations described above has generated new needs in terms of risk management. We will not go into detail about its development, but, in building the overall context of this research, would like to revisit some key moments marking its major developments.

Reason (1990) and Hale & Baram (1998) briefly recall the three main approaches to the management of safety prevailing in the 20th century. The first period from the late 19th century until the Second World War, according to Hale (in Hale & Baram, 1998) focused on the technical dimension. He recalls "*As UK factory inspectors in the late nineteenth state, the only accidents they were interested in having reported were those with technical causes, since (they considered) others could not reasonably be prevented*" (author, year? p.129). The 1920s were marked by the theory of individual accident proneness, which was succeeded by attention after the Second World War for ergonomic and cognitive factors. The concept of human error burgeoned between 1960 and 1980, becoming an overused and therefore unsatisfactory theme. The conclusion could be drawn that exclusive consideration of the technical and human dimensions proved to be a too limited way to study safety management in all its complexity (Hale & Baram, 1998). At the dawn of the 1990s, the socio-technical approach (Hale & Baram, 1998 and Reason, 1990) was gradually introduced (its practice was born with the introduction of audits of safety management systems, derived from the work of Heinrich, 1931[5]). This approach was an expansion on the practical approach and understanding of safety as an object of research and action, which developed in parallel with the growth in complexity of organizations managing a high risk business.

It was a series of well-known major accidents having disastrous consequences - Seveso (1976), Bhopal (1984), Chernobyl (1986), Challenger (1986), Piper Alpha (1988) to mention only a few - which generated a variety of in-depth analyses, such as the Columbia Accident Investigation Board (2003) and studies (Vaughan, 1996 and Shrivastava, 1994), or industrial research studies such as

[5] Heinrich’s work is indicated in this thesis but was not studied.

Dien & Llory (2004) or Lecoze & al. (2004). These researches highlighted the complexity of these events, demonstrated by the interdependence of many factors involved in the accident sequence.

This new approach ushered in the era of the study of "organizational accidents" (Reason, 1990). In this perspective, researchers now recognize (see for example Dien & al. 2004)), that critical events result not only from direct and immediate causes but also from the factors underlying these causes. Reason (1990) underlines the conclusion that the era of socio-technical analysis which is prevalent today has shown that most major accidents are rooted in the management and organizational sphere. According to him, errors or unsafe acts are caused by failures of decision-making. It seems now accepted, in the academic world at least, that analyzes of accidents and studies on safety management cannot be complete without recognizing and dealing with the complexity of the systems being studied. These findings have led to special attention being paid to the effectiveness of, and necessary changes to the systems of safety management in place in these high risk organizations, including the tools for studying and learning from events through Rex. The need to implement a program to translate research results into practical measures contributing to a more efficient safety management is a challenge addressed, among others, by Reason (1990).

2.2.2 Analysis of events: the emergence of the concept of weak signals

We have underlined, above, the importance which a multidimensional and organizational analysis of accidents has, translating as it does the necessity of understanding accidents in all of their complexity. Even though the purpose of this thesis is not to discuss the different models for accident analysis, it is appropriate to study the extent to which they can offer a relevant insight into the issue of weak signals. Accident analysis leads us to two sorts of fundamental conclusions:

-Complexity: accidents can be analyzed at different levels of "causality"[6], technology, human and organizational.

-Development: Accidents have a period of development (or incubation) in the course of which an organization can put in place measures to break the accident sequence.

The analysis of accidents, as a process of recognizing weak signals, constitutes the first pillar of my definition of weak signals.

[6] The term causality is put in quotation marks because it could be interpreted as an analysis in terms of a causal relation between a dependent and an independent variable. However, it has just been shown that accident analysis emphasizes interdependent relations (and not unique ones) between different variables. We may prefer accident "dimensions".

2.2.2.1 The complexity of accidents: multidimensional analysis

The work of Llory (1996), Turner & Pidgeon (1997) and Vaughan (1996) has at the heart of its analysis of events the notion of failing organizational factors. We have indicated above the need to analyze accidents at all levels (technology, human and organizational), because the social context and its surrogates produce new requirements for understanding these events and putting in place prevention suitable to their development.

Grabowski & al (2009) indicate that risk is a function of the probability and the severity of an unexpected event. A risk event is made up of root causes and proximal causes. An accident is an unexpected event having immediate negative consequences – an injured person for example – or a delayed effect. Risk events occur, according to these authors, because of a chain of errors, in other words a combination between root causes and proximal causes, which then leads to an accident. One of the keys to reduce risks is therefore to introduce barriers at appropriate (strategic) points in the chain of events in order to prevent the accident sequence completing itself. Many recent accidents (e.g. BP Texas City, see the report analysis of Deepwater accident in Delesalle-Stolper, 2010) show that the causes of accidents are becoming more complex. There is not only a linear interdependence between the factors causing the accident, but a more and more complex ramification of these factors. As Hale & al. (1997) and Reason (1990) have indicated, the need to take account of all of the technical, human and organizational dimensions in accident analysis is clear.

2.2.2.1.1 Cognitive analysis: human and organizational error

Grabowski & al (2009) have identified many models which facilitate the representation of an accident. They recommend the approach in terms of the evaluation of human and organizational errors which sees accidents, as indicated above, as a combination of factors situated at different levels in the organization.

The contribution of this classification (see figure 1) lies in the inclusion of errors not based purely on intentional acts, but covers also the conflict between a rule and the possibility (or not) of applying it. This shows that the resources provided by the organization – adequate training or clear rules – do not always enable individuals to handle in a safe manner. Here error is interpreted as a combination of individual and organizational errors.

These studies echo the approach to human reliability developed by De Terssac & Leplat (1990). According to them, human reliability depends on the match between the competences of the operator and task demands in the given circumstances. Analyzing errors allows the deficiencies in the system to be uncovered, and based on this, preventive actions to be taken to prevent future calamities. The same study underlines the fundamental concept of recuperation. An individual can be seen as a source of reliability to the extent that, according to the criticality of the situation, his expertise allows him to recover from a dangerous situation.

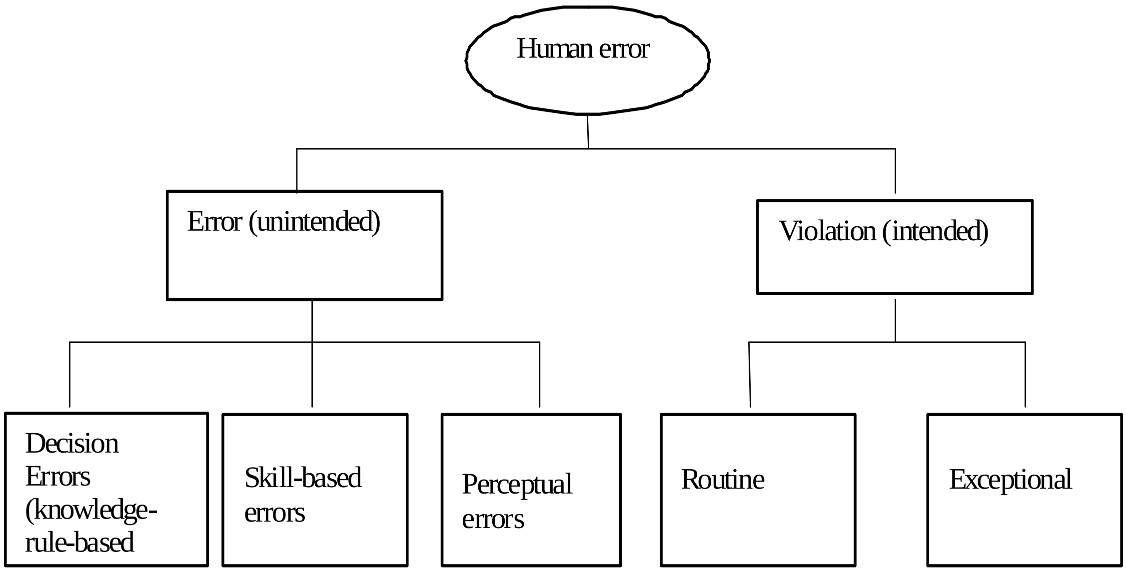

Figure 1: Human error classification (Grabowski & al, 2009).

These studies show that the idea of human error cannot be limited to an error – intentional or involuntary – of an operator. Broadening the scope to the organizational dimension contributes to the understanding of the need for the individual and collective dimensions in explaining accident sequences.

2.2.2.1.2 Organizational analysis: factors involved in accidents

The work of Dien & Llory (2002, 2004) is interesting for two reasons. On the one hand, it emphasizes the organizational factors which contribute to the accident sequence developing. According to these authors, these factors, identified from case studies, permit the drawing of more general lessons from accident sequences. These factors are transposable from one organization to another and can therefore be considered as generic and allow a transverse and "generalizable" reading of accident sequences[7]. On the other hand, based on this work to identify organizational

[7] This hypothesis can be criticized. In effect, it is necessary to show to what extent organizational factors involved in an accident sequence can be generic. Two opposing positions are tenable. These organizational factors could, on the one hand, be considered unique, both in their nature and in their implication in the accident; in this case it would be impossible to transpose the accident analysis using these factors into another organization. On the other hand, the lessons drawn could cast light on the organization, both in its structure and in its risk management, revealing traits which are to be found in many high-risk organizations: complexity, tight coupling and an uncertain, changing and menacing environment. In this case the organizational factors identified after an accident could, at least in part, be compared and transposed to other (similar) organizations. We take the latter view.

factors in accidents, the authors have endeavoured to describe means of action to improve safety management and reduce the occurrence of accidents.

The study entitled *Definition of pathogenic organizational factors in relation to safety* (Pierlot & al. 2006) offers a detailed analysis of six organizational factors found to be present in accident sequences. These factors are not claimed to be exhaustive or exclusive

1. Weakness of the safety culture of the organization in question

Culture, defined as the ensemble of practical knowledge and values possessed by the ensemble of members of the organization, can be inadequate through a lack of resources and competences, or deficient because of a gap between the values and the practices in an organization[?].

2. A complex and poorly adapted organization

Organizational complexity is defined as the combination of measures which complicate relations at work and the decisions and communications relevant to risks and safety. This complexity is due to the technology and the importance of the multiple 'silos' of the relevant parties[8], which make inter-organizational coordination difficult. This factor can be seen, according to Pierlot & al. (2006) as a risk factor. They point out rightly that the communication within the organization may be failing when the transmission of elements important for each person's work is not realized or is incomplete, and where informal communication does not always offset the failure in the formal communication. Coordination can in turn fail because of a bureaucratic organization, characterized by fragmentation and isolation of certain departments or work groups.

3. Difficulty in keeping alive the lessons learned

Pierlot & al. (2006) point to some weaknesses of the Rex which will be developed in the second section of this chapter, but we note here already:

- -Lack of means and resources allocated by the organization to maintain Rex processes
- -Lack of depth of analysis generated by the Rex (human and organizational factors are hardly taken into account).

4. Production pressures

They can be understood as pressures to ignore certain aspects of safety in order to prefer the criteria of profitability in the short term. The pressure arises when production activity is not balanced by a strong safety culture.

5. Risk Management

- -The design of the facility becomes pathological if its obsolescence is not detected.
- -The daily management of safety - practical implementation of safety requirements through the proper balance between the tasks to be accomplished and the skills present,

[8] It can be added that these 'silos' can equally apply to the departments within one organization, which affect the effectiveness of intra-organizational coordination. This point is fundamental in the treatment of weak signals, as will be shown in the last part of this chapter.

provided through appropriate training to ensure the transfer of safety know-how - may be insufficient when resources provided are scarce. It may be deficient when, despite the resources allocated, the objectives are not met.

6. Weakness in the regulatory authorities:

Although interesting, this last item does not appear in this literature review because it seems rather remote from our research topic.

Pierlot & al. (2006) identify these six dimensions that shed light on understanding the accident, dimensions that we propose to categorize as follows: safety culture, organizational structure, risk management, the processes/management tool relating to risks, and the environment. They decipher the organizational factors as elements, not exhaustive, contributing to the accident sequence. Second, they emphasize the importance of allocating resources to maintain reliability. These resources can also be categorized: technical resources, availability and reliability of equipment, human resources, trained operators and skilled resource management, clarity of tools and modes of communication, internal and external organizational resources and finally, a structure appropriate to the activity and existing resources. These means and resources can be considered as levers to counter the failures of the factors identified above. However, these items are not integrated into a model such as the Delft model which we describe later in section 2.3.3, but they provide information in a clear and empirical way about the importance of considering the accident as indicative of shortcomings in organizational factors which, combined with a trigger, can start an accident sequence. One of the challenges of the problem of weak signals is early identification of failure in these factors.

2.2.2.1.3 Accident "waiting to happen" and normal accident

Normal accident theory (Perrow, 1984, Bourrier, 2001) led to the identification of systems for which the design and type of activities practiced could be intrinsically the source of disasters. Rijpma (1997) reminds that normal theory accident is characterized in the first place by complexity. When an organization has to face a complex technology, unexpected interactions between different dysfunctions can intervene, dysfunctions which the operators cannot anticipate and control (Roux-Dufort, 2003). Secondly, normal accident theory is characterized by "tight coupling": an error or deviation triggers another very rapidly, leaving a very low margin for operators to intervene (Hopkins, 1999). When a system is complex, in the sense of Perrow, and at the same time tightly coupled, accidents are considered in this theory to be inevitable. Hopkins (op. cit.) notes a contradiction in relation to the organizational structure needed to cope with emergencies. He underlines that, in a system defined by a tight coupling, authority must be centralized, i.e. the operators are supposed to act according to predetermined directives. Whilst, in a complex system, a decentralized decision-making would allow a better anticipation of, and coping with the diversity of the situation and its potential errors.

The main contribution of Perrow's research (1984) is the following. The complexity of organizations at risk - whose main characteristics are defined above - generates difficulty at an individual level - the operators - and an organizational level to perceive the signs of a decline in safety level. These signs or signals are spread out within the organization because of a complex and fragmented organization, and evolve quickly because of the tight coupling of the activity. He therefore concludes that it is difficult, or even impossible, to anticipate such errors or their propagation as long as the organization and its activities remain complex. Decentralizing authority, as Hopkins (1999) suggests would allow individuals to intervene faster when safety deviations are detected. But Bourrier (1999) underlines the limits of the theory of normal accidents. Although she recognizes the contribution from the characterization of certain type of organizations, she notes that the theory of normal or systematic accidents leaves little initiative to the actors in the system, betraying a holistic vision, where the socio technical-system is imposed upon the actors.

To summarize, accident analyses make a first essential contribution to the work of this thesis, namely underlining the importance of tackling accidents with a multidimensional approach and identifying organizational factors playing a role in the genesis of an accident. This perspective helps us to overcome the simple explanation of major accidents, disasters, crises or incidents as having only a technical cause or a human error, and adds a description of the complexity of the observed systems. This leads us to the conclusion that the genesis of accidents can be explained by a failure of the system, and more particularly in its capacity to maintain the elements of this system - technical, human and organizational - in a state of reliable functioning.

We turn now to the second dimension, the development or preparatory phase of the accident.

2.2.2.2 The development of the accident: emergence of information alerting to a threat to safety

2.2.2.2.1 Medical metaphor

Many authors agree about the existence of latent conditions in the genesis of an accident, which therefore does not arise "accidentally"("by chance") but because of the combination of a number of factors waiting for a trigger. This view of accidents is important because it adopts an important theoretical and practical stance. As suggested by Reason (1990), this view indicates that underlying factors can be identified by an in-depth and detailed analysis of the organization and, in particular, that this paves the way for a better prevention of the occurrence of accidents (we will develop this issue further below). The incubation period (Turner & Pidgeon, 1997) for these pathogenic factors (Dien & Llory, 2006 and Reason, 1990) has a rich learning potential. It allows us to identify a phase or stage in the preparation of the accident or crisis which, contrary to the accident itself which takes place over a short period, develops over a long process of maturation (Dien & Llory, 2006). In spite of the importance of the incubation period, it is very often identified only a posteriori, with hindsight after the event. Based on this view of accident analysis and research into emergencies, we show the extent to which this notion of an incubation period contributes a relevant set of knowledge to the issue of weak signals.

The notion of an incubation period is taken directly from medical science. Incubation is the period situated between the contamination of a body and the appearance of the first symptoms. In the field of toxicology, contamination indicates the invasion of a living body by pathogenic microorganisms or unwanted toxic matter. A symptom is a "*morbid event in connection with a medical condition. The symptom is perceived by the patient and is opposed in principle to the signs or objective findings discovered by the doctor*" (Grand dictionnaire terminologique, Office québecois de la langue française, 2011). The importance of this medical metaphor is twofold. In the first place, it proposes a parallel between the contamination of a body and that of the organization, by pathogenic bodies coming to weaken the capacities of that body to defend itself. We can, and have the time therefore to, look in advance for the signs of this contamination and the weakening of the defenses. Secondly, and what interests us more exactly, the symptoms which appear during and after the incubation period do not easily allow us to identify clearly the disease which is incubating. Their meaning remains ambiguous and uncertain. We retain these elements because they will be fundamental in the definition proposed in section 2.4.

2.2.2.2.2 Accident incubation or preparation

We conclude that accidents know a preparatory phase, during which the signs of potential threat to safety appear. Turner & Pidgeon (1997) defined the accident incubation period as a process during which the organizational factors are linked together to prepare the accidental sequence. They distinguish six stages in the genesis of a disaster:

-The point of departure lying in the beliefs and risk perceptions pertaining in the organization and determining the management of a potential accident,

-The incubation period,

-The event which precipitates the accident,

-The emergency rescue and recovery,

-The necessary cultural adjustments post-accident.

We concentrate here on the incubation period during which events develop and accumulate without being detected for a number of hypothesized reasons:

-Inadequate hypotheses about the real existence of signs of system degradation,

-A difficulty to handle information in a complex situation; important messages are lost or flooded by the background noise,

-A hesitation to envisage the worst; danger is often underestimated/undervalued

The incubation period is defined by these authors as the emergence of events which are at odds with the standards and beliefs individuals have built up about the risks. The notion of incubation period shows that this preparatory phase of the accident is characterized not only by an accumulation of technical, maintenance or management failures, but by a difficulty to observe the signals alerting to a potential threat to safety. From a sociological point of view, which we take here, we conclude that the organization has difficulties to make sense of signals which could transmit relevant information and to interpret them as threats on safety. The basis of this weakness lies in the organization, particularly in the beliefs and perceptions about the risks that individuals have forged, in the procedures for disaster management and in the evaluation of the probability of its occurrence.

In a similar perspective, Roux-Dufort (2003), in his book entitled *Managing and deciding in a crisis situation*, proposes a synthesis of works on conditions in which crises arise. A crisis begins with a subterranean phase. Errors and dysfunctions may occur, as in many organizations. During this phase, the errors are hardly visible because they get swamped in the daily activities of the company and can pass unnoticed. If they are not corrected, they become embedded and accumulate to provoke deviations.

These researches lead, according to us, to two conclusions. In the first place, the notion of the incubation period suggests that we consider the genesis of a disaster or a crisis as happening over a long period, which we can therefore look out for, but also one where there is an accumulation of deviations or errors which become embedded insidiously within the organization – weak signals. Secondly, the reasons why an organization may not perceive errors or signals of a threat to safety are to be found in the perceptions anchored at the same time in practices (daily activities, maintenance, and management) but also in beliefs and culture. However, Turner & Pidgeon (1997) speak of this phenomenon only in generic terms. Their research leads to the identification of factors blocking the treatment of the emerging signals during the incubation period, but less to ways of responding to them.

2.2.2.3 Pathogenic factors: from diagnosis to treatment

Reason (1990) makes a distinction between active and latent errors of technical systems. The effects of the active errors reveal themselves almost at once, while the latent errors have consequences which can stay sleeping in the system and show themselves only when they combine with other factors. For him, accident analyses (he studied famous disasters such as Bhopal, Challenger, Three Mile Island, Flixborough) show that latent errors are the most important threats to complex systems safety.

The metaphor of resident pathogenic agents (inspired by the medical analogy) has two things to say for our work. Not only does it allow us to identify the pathogenic factors in their causal role in the genesis of an accident but it also opens possibilities for action. In a complex system, characterized by Reason as tightly coupled, with strong interactivity and opaqueness (a definition comparable to that proposed by Perrow), the causal factors of an accident are present long before the accident occurs (which confirms the notion of the incubation period). The system has latent failures whose effects are not at once visible but can favour dangerous actions. The notion of resident pathogenic agents emphasizes the need to search for the indicators of morbidity of the system before an accident. We can hypothesise that the probability of an accident is a function of the number of pathogenic agents: the higher the number of pathogenic agents, the higher the risk of genesis of an accident. Also we can hypothesise that the more complex the system is, the higher may be the number of pathogenic agents. The theory of pathogenic agents allows us to look for the indicators of morbidity prior to the accident, and supposes that it is possible then to remedy them.

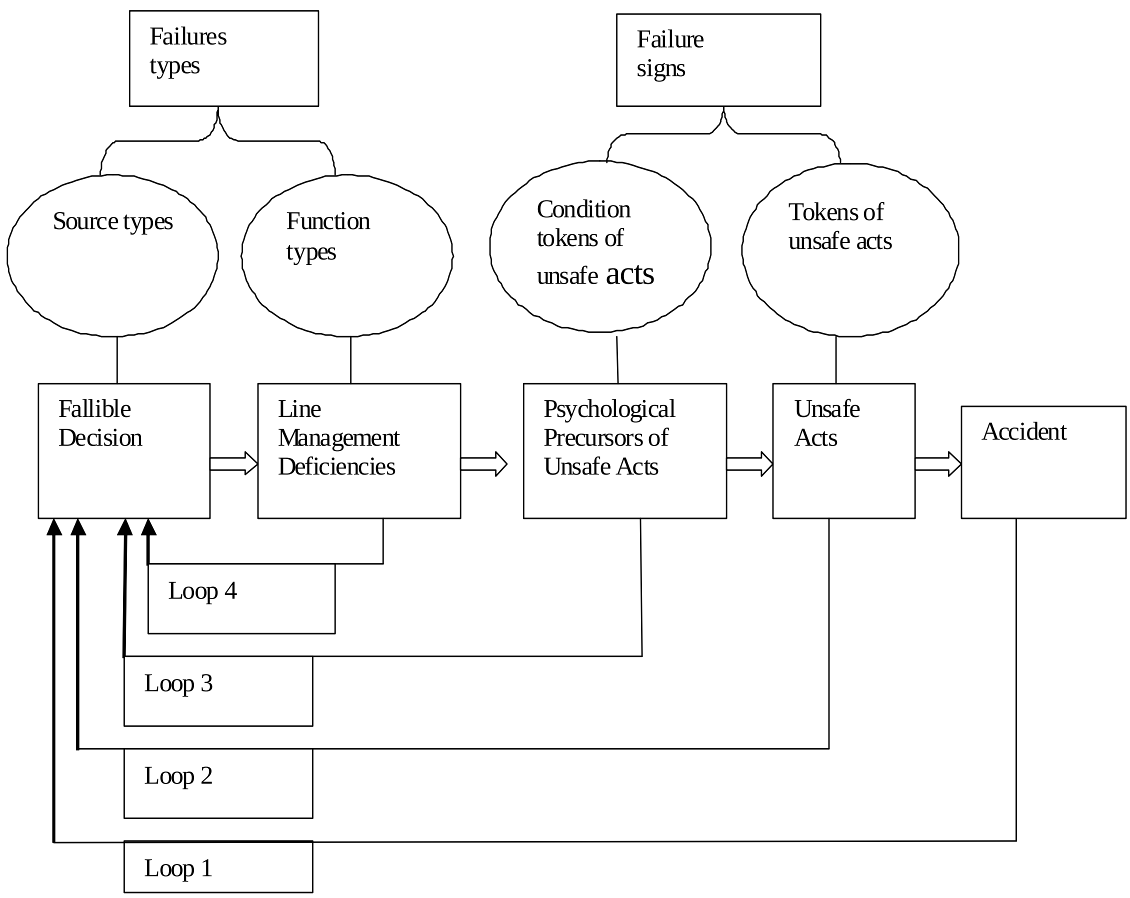

Figure 2: Feedback loops and indicators (Reason, 1990).

Figure 2 summarizes Reason theory (1990). Reason considers that it is possible to identify and to neutralize the pathogenic factors by acting directly on them. According to him, and it is also our objective, the best contribution to manage safety effectively is to realize feedback loops 3 and 4 (figure 2) that is to act on the types more than on the tokens - in other words to act more on the deep organizational causes and less on the symptoms of these causes, by acting on the states of the system arising early in the accidental sequence. Reason writes: "*The major challenges for the specialists in human factors, who are interested in the protection of safety of complex and very dangerous systems, consists in identifying these types of failures and in finding the means to neutralize the pathogenic agents*" (p. 284). The types of failure identified by Reason would be the failing organizational factors - to be identified upstream - and the manifestations of those failures as defects (latent, persistent but untreated anomalies). The feedback loops presented in figure 2 make implicit reference to the notion of organizational learning. Loop 1 is reactive, because the identification of the types of failure happens only after the accident, in contrast with loops 2, 3 and 4 which are proactive, because no event has happened to help to identify either the tokens of the types of organizational failures (for example near misses or other abnormal situations). We can thus note two levels of learning. The first one is a reactive learning and the second proactive learning.

These propositions provide very interesting keys to tackle the issue of weak signals. Following Reason's works, we hypothesize that weak signals emerge and find their roots in organizational factors. Thus, responding to weak signals implies identifying these causal factors and acting on them in order to neutralize them. By doing so, we believe that any organizations running a risky activity can learn from critical events and improve its learning process.

To summarize, the works which we have presented in this section show that accident analyses have demonstrated:

-The importance of considering critical events in their complexity

-A preparatory phase of the accident during which signals of the degradation of the safety system appear without being handled in time

-Finally the possibility of identifying and acting, upstream, on the failing organizational factors and of influencing the accidental sequence. Weick (1990) writes on this issue that, to anticipate disasters or crises, it is necessary to observe the regularities with which the events come together to produce effects with major consequences.

The following section of this chapter tackles one of the main tools of critical events analysis used by industrial sites: Rex. Despite the contributions made by this approach as a vector of knowledge on the critical events and their origin, we will show that many limits to its contribution have been observed.

2.3 Safety management: from technical to organizational learning

Rex is one of the methods used in the French industrial upper level Seveso sites to ensure the reporting and analysis of critical events. This method has two purposes: reducing accident occurrences and facilitating the capitalization/accumulation of knowledge relative to these events within the organization, in order to improve safety management. Rex contributes to improving critical events management but contains also some limitations, which means that Rex often seems to fail in these two purposes despite a systematic use and formalized structure.

Rex, as the attempt to capture and integrate weak signals in safety management, constitutes the second focus of our work.

2.3.1 “Retour d’Expériences”: context and definition

2.3.1.1 Different perspectives

The May 10th, 2000 decree requires upper level Seveso industries to adopt Rex in the following way: "*Procedures are to be implemented to detect accidents and near-accidents, in particular when there were failures of prevention measures, to set in motion investigations and necessary analyses, to remedy detected failures and to ensure the follow-up of corrective actions. Regular reports are to be made*" (Extracted from the May 10th, 2000 order, Appendix III). This definition includes several elements. Rex is a global formalized approach combining analysis, corrective measures and actions following critical events.

A whole body of literature (Amalberti & Barriquault 1999, Dien 2006, Gilbert & Bourdeaux 1999, Wassenhove 2004, Rakato 2004) tackles Rex as an object of research. More exactly, some authors have attempted to show the contributions and the limitations of this approach, both in practical and theoretical terms. These works “go beyond” the simple formal description of Rex (as does the decree) to the core elements of Rex, to include its purpose, the objects to be covered (near misses, critical events and good practices) and its method’s contributions and limits.

Rex is usually defined according to the following stages (Gaillard, 2005):

-Detect and analyze anomalies, deviations and events,

-Look for the causes and the sequences of these events,

-Learn lessons from them,

-Define corrective measures and improvements,

-Ensure the relevant information to stakeholders

The following sections tackle these issues.

2.3.1.1.1 Generating knowledge

Wassenhove (2004) describes Rex as a process consisting of methods and procedures to learn lessons from past activities. It allows the identification of methods leading to success, the measurement of the efficiency of actions, and the capitalization of the experience by facilitating the development of good practices. This formalized Rex takes shape at three levels (Wassenhove, op. cit.): individual (personal contribution), at team level - implementation of meetings for appraisal of performance and methods - and at organizational level – learning agency supervising the learning process. In the field of risk management, Rex should allow a better exploitation of lessons learned from accidents, from a technical, human and organizational point of view. Rakato (2004) suggests defining Rex as an approach structured by capitalization and by exploitation of the information stemming from the analysis of both negative and positive events. It coordinates a set of technical and human resources that must be managed to contribute to a decrease in error recurrence and to facilitate successful practices. Rex is considered, in summary, as an approach, formalized thanks to knowledge management, intended to reduce the occurrences of accidents.

Finally, according to Becker (in Hale & al., 1997), incident reports and event analyses aim to improve safety by identifying sociotechnical system weaknesses and, by feeding the information, to the competent units of the organization so that they can implement the necessary changes. Incident reports and events analyses are essential elements of Rex. One of the challenges is to succeed in managing well the knowledge produced by these events.

It seems to be demonstrated through these studies, that formalized experience feedback allows not only the reporting and analysis of critical events, but also the learning of lessons from it. We turn now to the question as to what knowledge is exactly generated by Rex.

2.3.1.1.2 Covering the spectrum of risks: three Rex practices

The objects studied by Rex vary according to several factors: the definition of the Rex according to the company and its domain (chemistry, transport, energy) and the degree of involvement of the company in the implementation of a policy of Rex. Gauthey (2005) proposes three types of Rex:

-"Event-based" Rex; from significant events,

-"Weak signals” Rex: from the incidents and the anomalies,

-Experience Rex: relating to "good practices".

Despite this variety of objects Gilbert & Bourdeaux (1999) underline points of convergence. We follow Gauthey’s typology to develop the sections which follow.

Rex relating to significant events seems to be the one most implemented in industrial plants (Gauthey, 2005). Significant events mean prominent events which necessarily call into question current practices and whose potential or actual consequences are severe. Gilbert & Bourdeaux

(1999) specifiy that organizations cannot ignore an accident. The facts and their consequences are too important. By definition negative, they represent a failure of the organization in its capacity to manage the risks and more particularly to avoid the development of an accident. So, the events reported and analyzed via this sort of Rex are prominent in their nature and their consequences, but also in their symbolic significance. Accidents are painful experiences not only for the site itself but also for all stakeholders (locals, authorities, company headquarters, regulators) which may increase the severity of the event. However, Gilbert & Bourdeaux, in their work entitled "*Procedures of experience feedback, organizational learning and awareness*"; show that limiting Rex to the study of accidents (or similar significant events) may restrict the lessons to be learnt from these events. Accidents are in fact - and fortunately - rare. Extending the analysis to incidents, near misses, or even successes – situations where errors or deviations have been recovered - would extend the cover to a wider spectrum of events and so enrich the knowledge of the organization on the risks inherent in its activity. We deal with this in the next section.

Some authors such as Becker and Hale (in Hale & al. 1997) propose enriching the Rex about significant events with practices intended to **report dangerous situations upstream of these critical events**. Hale (1997) proposes to pay attention to near-misses that have stopped in time before the consequences are catastrophic. This would represent an opportunity to analyze the mechanisms of operator's recovery. Amalberti & Barriquault (1999) suggest putting in place a Rex on minor dysfunctions. These incidents may be harmless but may have significant potential effects on performance. Rex on minor events would enable the organization to learn from the normal functioning of complex systems, insomuch as they would reveal the nature of actors' decision-makings to recover errors or deviations. Taking account of these less significant events (or minor events) would have the advantage of expanding the nature of events to be analyzed as part of safety management and thus improve the knowledge of the site not only on its diversity and the complex situations it may encounter, but also on professional practices and specifically the mechanisms of error recovery implemented by the operators (or persons involved in maintaining safety). This practice can be characterized as feedback of "weak signals" as it pushes an organization to observe any type of event upstream events that generates significant learning convincing. Hale (2001) warns that care should be taken with extending incident analysis to minor events, especially if this is being done in the name of better prediction and control of major accidents using the concept of the accident triangle devised by Heinrich (1931). Only some minor incidents lie in the same scenarios as major accidents, whilst many others have no potential to escalate beyond a minor injury. Pursuing the latter in the belief that their prevention will assist in major accident control leads to a false trail. Expanding the scope of Rex by adding other types of event in the search for weak signals should not be confused with deepening the analysis to cover underlying organizational factors of incidents with more major potential or actual consequences, where the truly weak signals lie.

The studies presented above consider Rex as a comprehensive approach combining experience feedback on significant events, and, in addition, the reporting and analysis of failures and anomalies which could have significant effect. This combination of practices would respond to the criticism made by Gilbert & Bourdeaux (1999), to cover more broadly the types of events that can occur on a site. This type of feedback could represent a major breakthrough in the design of Rex in so far as it would report and analyze events upstream of the accident sequence. It does, however, need to beware of watering down the learning by flooding the system with minor anomalies with no potential to be more disruptive. However, Gauthey (2005) admits that a Rex for the weak signals is difficult to implement. He writes: "*Experience shows that this form of feedback (weak signals) is much more complicated than the feedback on significant events and its implementation requires teams of specialists experienced in detecting weak signals and their treatment. Thus, this form of feedback is not practiced by all companies encountered, and those which try to do it recognize the difficulty of this practice* "(p. 12).

The third practice of experience feedback is the **detection and promotion of good practices**. Gauthey (2005) states that the feedback of "good practice" is still in its infancy, given that industrial sites still widely apply Rex only to significant events. The interest of identifying best practices lies in sharing knowledge by dissemination of lessons within the organization and between organizations (inter-site experience feedback). Tsang (1997) writes that the modalities of knowledge sharing must depend on the modalities of organizational coordination. There are two types: a hierarchical, formal structure, and a structure organized around informal and lateral relations. The first type of coordination, characterized by centralization, tends to reduce the initiative taken by actors in the organization, their exchange of knowledge and thus the capacity for knowledge transfer. The second type of coordination allows, unlike the first, a transfer of knowledge through informal channels of coordination. By surpassing the boundaries of formal organizational structure, these channels promote the construction of common and mutually shared interests.

Despite the diversity of practices of Rex and the effort made by industrial companies to put them in place in the plants, many studies have highlighted the limitations of experience feedback as learning process.

2.3.1.2 The limitations of "Retour d'Expériences"

Studies that have examined the foundations and the effectiveness of the Rex approach agree on the fact that it is often reduced to an analysis of the technical aspects of reported events. By doing so, industrial sites stay within the area of what they see as the manageable, and actionable (Gilbert, 2002). In this context, Rex most often leads to technical change (replacement or renovation of equipment for example). This limited action could give the illusion that the problem is solved (Dien & Dechy, 2007) and would be consistent with the engineering culture which is still predominant in such industrial plants. The same authors (Dien & Dechy, 2007 and Gilbert, 2002) have shown the insufficiency of the technical dimension in understanding the dynamics of an accident, and have underlined the importance of incorporating organizational and human factors. The latter two dimensions seem difficult to take into account for at least three reasons:

-Problems in defining and identifying what are effectively the human and organizational factors. We opened above one possibility to resolve this by considering the weak signals Rex as an opportunity to observe the practices of operators' recovery from incipient error, and therefore the mechanisms in a team of operators to maintain safety at an optimum level. But faced with the difficulty of setting up this kind of feedback, the ability to integrate human or organizational factors seems still difficult.

-Problems in having the necessary skills and competence to analyze these factors, that is to say experts in human and organizational factors dedicated to accident and near miss analysis.

-Problems in finding ways to integrate these factors into the industrial culture, that is to say to promote the transition from an engineering culture to a safety culture, taking into account all aspects of the organization.

The limits of Rex that we have identified are widely observed also by practitioners. Dien & Dechy (op. cit.) believe that the Rex has reached its limits, because of the repetition of industrial accidents. Despite the introduction and use of Rex on significant events within sites running a high risk activity, and complementary practices devoted to report minor events or good practices, it seems that the Rex approach shows a lack of efficiency in the two aims it pursues: the prevention of accidents and the promotion of organizational learning.

Three assumptions help us to understand these limits, which we deal with in the next two sections.

2.3.1.2.1. "Retour d'Expériences" formalization: necessity or bias?

Gilbert & Bourdeaux (1999), Bourrier (2001) and Dien & al. (2004) observe that Rex, as practiced and implemented in risky industries, is highly formalized. The different phases of Rex, within sites, appear to respond more to a necessity of compliance with the legal requirements and procedures than to any real and (self-) critical process of safety management and learning. Reporting and archiving appear as central activities in Rex, rather than learning (Gilbert & Bourdeaux, 1999). Hale (2003) highlights the relative failure of reporting systems of accidents and incidents. Some companies seem to believe that it is sufficient to place all of their concentration on collecting data and to leave worrying about how to analyze them to later, instead of matching the data collection to the needs of the analysis. This task (data analysis) is often underestimated because it requires organization and resources which are often allocated improperly or insufficient (Koornneef, 2000). Thus, one of the pitfalls of Rex would be to "run dry". This excessive formalization tends to blind the whole Rex system and those involved in making it work to the purposes of this approach.

2.3.1.2.2 Increase in the number of tools and Rex reactivity

Rex is not a single tool. As noted by Gauthey (2005) in his inventory of Rex practices, industrial sites implement a variety of tools to report, analyze and treat various types of events detected on a production site. In this context, databases accumulate and therefore complicate the management of data reporting via Rex and its integration into a clear overall picture of what needs to be learned and done. The question of how these data are managed will therefore be an important issue for study in this thesis. We hypothesize that organizations running a risky activity accumulate safety management tools without extracting lessons and knowledge from databases. This question is raised in chapters 3 and 4 (the case studies) where we try to provide some answers.

Finally, Bourrier (2002), Dien (2006) and Amalberti & Barriquault (1999), noted that Rex seems to remain reactive (applied mainly after the event) and changes little towards a "proactive" approach (despite the practices of reporting "weak signals") aimed at solving the problems identified.

2.3.1.3. Conclusion

These limitations, defined by several authors provide us with working hypotheses for this thesis. They suggest why learning about weak signals has been relatively unsuccessful up to now. The challenge for this thesis is to overcome these limits and to propose changes to improve the effectiveness of Rex and, by extension, opportunities for learning.

We have presented several Rex practices, relating to significant events, weak signals and good practices. These different practices are intended to cover the spectrum of risks inherent in an industrial site and its activities. The establishment of a Rex “weak signals” can introduce the site to a proactive risk management, allowing a better opportunity for learning. However, many difficulties may curb this process. Rex as practiced now is formalized and reactive, but also seems to focus only on the technical aspect of the events reported, giving little insight into the human and organizational factors. Reported data suffer from a lack of detailed and deep analysis to arrive at underlying weak signals. This tends to limit the current Rex approach to simply archiving data collected on the site or on other plants of the same company. In its current implementation, the feedback does not always respond adequately to the aims it was designed to pursue, namely:

-Reduce the occurrence of accidents,

-Identify and integrate the weak signals of accidents,

-Promote a process of organizational learning.

Rex seems to be mostly failing in its purpose of learning. To overcome this limitation, we propose in the next section to present the work on organizational learning and analyze how they can be a relevant input for improving Rex.

2.3.2 Organizational learning: condition for a successful “Retour d’Expériences”?

Learning from past events is a method providing learning to sites managing a risky activity. However, the implementation and use of this method has some challenges. They result, for the organizations involved, in a difficulty to draw lessons and learn from events (accidents, near misses and abnormal events) analyzed by the Rex method. One of the challenges of the organizational third age of safety (Hale & Hovden, 1998) is precisely to link, according to Hale & al. (1997), event analysis and safety management in a perspective of learning. The first difficulty of such a project lies in the challenge of the complexity of the organizations in which accidents are analyzed. The organizational determinants of injury are more distant in space and time from the accident. Hale & al. (1997) raise a simple question, but the realization is complex: what can be put in place so that the past does not repeat itself and so that there is a reduced probability of occurrence of critical events in the future? Organizational learning promises such a bridge, albeit a difficult one, between the painful experience of the past and the possibility of building a more solid reliability for the future. In this sense, accidents offer a learning experience in so far as they identify points of weakness that contributed to the accident sequence and it becomes possible to correct but also to improve the principles, methods and accident prevention tools developed by the organization to manage the system in question. Organizational learning has therefore as its first objective promoting an approach reconciling the past and future of the organization.

The second difficulty lies not in the temporal dimension, but in expanding the investigation or analysis required by organizational learning. Investigations of a judicial nature are characterized by Hale & al (1997) as ones trying to find a culprit to blame, or punish and a person to pay for the repair of the damage to the victims. They are often limited to the direct causes of the accident concerning the behaviour of the operator and technology. An organizational level approach questions the organization at all levels from the front-line operator, through the local management to the company directors. In summary, organizational learning opens the analysis of events:

-In time, through a search for causes in the past,

-In space by examining all levels of the organization

The objective of organizational learning is to establish an organization which can learn from its mistakes and is able to learn from the past and anticipate errors, failures or events proactively, without waiting for the occurrence of a crisis or a dangerous situation.

2.3.2.1 Descriptive approach: informal dynamics of organization learning

The works discussed below shine a light on the learning process and the factors both endogenous and exogenous that contribute to the development of learning. This process can encourage successful organizational learning even in informal ways, but the implementation of a formal or prescriptive approach may better promote its effectiveness and efficiency.

2.3.2.1.1 Organization learning process

Wassenhove (2004) defines a learning organization as an organization open to learning. This puts the emphasis on the process of learning rather than its result. For Senge (quoted in Wassenhove, 2004), a learning organization considers learning as a core value and as a part of the organizational processes. This requires a change in mindset and organization. Argyris & Schön (2002) in turn, emphasize the notion of needing to produce change that proves that organizational learning has taken place. We shall see later that organizational learning commences when the values and norms that underlie the actions of individuals are questioned and is complete when measures have been implemented and appropriated by those individuals. Change and organizational learning are two concepts that overlap and complement each other.

This approach requires clarification of the theoretical framework in which this concept is conceived. We have identified two theoretical frameworks: the systemic approach and the constructivist approach in the sense of Berger & Luckman (1966).

Fillol (2004) proposes to study learning based on an "open system" that is to say a set of interacting elements forming an unit composed of parts and interacting with the environment. In this context, the organization imports information from outside and develops a capacity to learn from this information[9]. A systemic approach therefore considers organizational learning as a

[9] The study presented in this section tackles the issue of an organizational learning approach in a context of "veille stratégique" (strategic overview) to maintain an organization in a competitive market. This explains why the author focuses on information detected outside the organization. When considering learning in relation to safety, we believe that the information from the internal activity of the company must also receive attention because it has a strong

phenomenon of acquisition, processing and learning on the basis of information received from the environment (or from within the organization) in order to remain innovative and flexible (Huysman, 2004). Only such learning organizations can be considered able to cope with a changing or turbulent environment. Tsang (1997) in turn emphasizes that learning allows a better business performance. Information management to Rakato (2004) is a major challenge of companies. By expanding their field of vision, companies can detect threats more efficiently. This requires, again for this author, a capacity to learn and adapt to a changing environment (changes noted by Rasmussen, section 2.2.1.1). Guided by the work of Ansoff & McDonnell (1990), Lesca & Castagnos (2004) show that, when threatened by a changing environment, the more a company can develop its intelligence capability, the more it will be able to detect and anticipate changes, disruptions and unexpected events, and the more it will remain competitive.

This idea is appealing, but it does not develop in detail the process to be implemented on receipt of this information, the nature of this information, and finally the process of converting this information into knowledge. There is also no evidence to determine to what extent the organization as a whole learns. Thus, these studies are unclear about the difference between individual learning and organizational learning - and therefore on what is the subject or the object of learning, indicating a difficulty to conceive of and demonstrate learning at a collective or organizational level.

Huysman (2004) proposes a constructivist approach to organizational learning, inspired by the social construction of reality developed by Berger & Luckman (1966). Organizational learning is analyzed as a process of institutionalization through which individual knowledge becomes organizational knowledge. Institutionalization implies that practices become regular or customary for individuals in the company, and hence institutionalized. Institutionalization covers three stages: externalization, objectification and internalization. In the context of organizational learning, externalization means the sharing of individual knowledge with other members of the organization, through formal or informal channels of communication. Objectification covers the acceptance of this shared knowledge by members of the organization. This acceptance through the objectification of knowledge shared shows the link between individual learning and organizational learning. Finally, internalization is the appropriation of the knowledge by members of the organization to make it their own and to become "insiders" (Huysman, 2004, p. 36).

This second approach provides an interesting perspective. It strives to explain by what social process individual knowledge may become socially accepted and institutionalized. Without referring explicitly to Berger & Luckman, Fillol (2004), but also Argyris & Schön (2002),

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potential for organizational learning as it transmits signals about the developments of changes in the organization's internal activity.

recognize that organizations learn through the individuals who compose them. The "knowledge spiral", a concept developed by Nonaka (quoted in Fillol, 2004), describes a process of diffusion and spread of knowledge through exchanges and relations between members of the organization. Two processes may facilitate the passage from tacit knowledge to explicit knowledge (or from individual knowledge to collective knowledge): externalization through the use of figurative language and symbolism, and internalization. In the internalization process explicit knowledge is diffused through the company and becomes tacit and integrated in the routines and patterns of individuals who compose the organization[10].

This work has the advantage of describing the learning process by focusing on how to transform individual learning to organizational learning and thus create conditions for the success of this learning. But other works such as Vaughan (1996) throw light on blocking processes which hinder organizational learning. We turn to those in the next section.

2.3.2.1.2 Organizational learning blockers

Learning can be blocked. Vaughan (1996, see also Bourrier 2001) conducted an ethnographic and historical analysis of the accident to the space-shuttle Challenger. Her work led her to develop the concept of "normalization of deviance". In analyzing the history of decisions prior to launch of Challenger in 1986, Vaughan, in her book *The Challenger launch decision: risk technology, culture and deviance at NASA* showed that the managers and engineers responsible for risk analysis had normalized anomalies observed on the O-rings after each mission. Normalization meant in this context that the accumulation of information which had been first analyzed as signs of potential danger were, on reflection, reinterpreted as acceptable and not deviant (Vaughan, 2001). These technical deviations had become normalized (Vaughan 2004). We believe that this constitutes a failure of learning, as suggested by Macrae (2007) to the extent that the weak signals of deviation or error have been normalized, that is to say, after analysis, redefined as acceptable practices. We will see in section 2.4 factors of blindness and logic that can lead actors to normalize such errors.

The failures in learning are defined by a difficulty on the part of the organization, to observe, take into account and respond to signals showing threats to safety. This reflects a double difficulty: the openness to and the transformation of data from the environment or from the system's collective (internal) knowledge.

The informal learning processes described above have a double interest. On the one hand they serve to underline the elements of successful collective learning, the passage from individual

10 We should add that only part of tacit knowledge may be turned into explicit knowledge.

knowledge into collective knowledge. On the other hand, they show that this transition may not take place and thus lead to a failure of learning. To ensure its effectiveness and success, should organizational learning be formalized? This is one of the goals we put forward in the next section.

2.3.2.2 Formalizing organizational learning?

Koornneef (2000) has contributed through his research to the building of a formal model of organizational learning. The following section presents the benefits and limitations of his work.

2.3.2.2.1 Organizational learning has to be organized

A key contribution is that of Koornneef & Hale (in Andriessen and al., 2004[11]). Inspired by the work of Argyris, they used the concept of organizational learning in the context of organizations managing risk and showed more precisely how an organization can learn from unexpected events or surprises[12] (Koornneef, 2000). For an organization to become a true "learning organization", it must organize learning. Several components are essential to achieve this process (figure 3). Surprises are the basis of the events that the system handles. Only the unexpected or unanticipated events need to be notified. The ability to observe an incident as a surprise depends on the observers, their experience or their professional habits. Some operators may be more sensitive to surprises than others. It therefore becomes necessary to train and accustom the observers to be alert to surprises so that learning, on the basis of the treatment of such events, is optimal. The detection of weak signals requires, also according to Ansoff & McDonnell (1990), a special sensitivity and expertise on the part of observers. While Koornneef (2000) places the operator as a principal actor in this detection, Ansoff & McDonnell (op. cit.) proposed the use of three types of actors.

-Outside experts

-Actors-with an interface function

-Actors with extensive contacts within the organization.

These "surprises", once detected, must be notified, according to Koornneef (op. cit.) to a "Learning Agency”. This agency needs to consist of some members closely related to practice and others able to stand back and review it dispassionately, and needs to have the resources to carry out

[11] We will mainly refer to Koornneef F. and Hale A., (2004), “Organised memory for learning from operational surprises: requirements and pitfalls”, in Andriessen J. H. E. and Fahlbruch B., *How to manage experience sharing: from organisational surprises to organizational knowledge*, Emerald Group Publishing, United Kingdom, to develop Koorneef’s works.

[12] We return to the concept of surprise in the third section. The problem of weak signals in fact shows the importance of habit in the observation of unexpected events. Trained domestic observers can be supplemented by the intervention of outside observers, who can ensure a fresh eye. This links to the idea that it is necessary or essential to relax or revise the interpretive frames of observers, in order to promote attention or vigilance.

its two main roles. It first promotes the relevance and value of information reported by resituating it in the context in which it was detected, and helping to find additional information to that detected if necessary. Secondly, this Agency can play an intermediary role between individuals and the organization, analyzing the incidents or surprises notified by the operator and disseminating lessons that must be implemented by the business unit and organization. Lessons are learned once the solutions found to deal with the surprises detected are implemented and can prevent the occurrence of further incidents. Organizational learning has occurred when the practices, but also the values that underlie them (double-loop leaning), have changed.

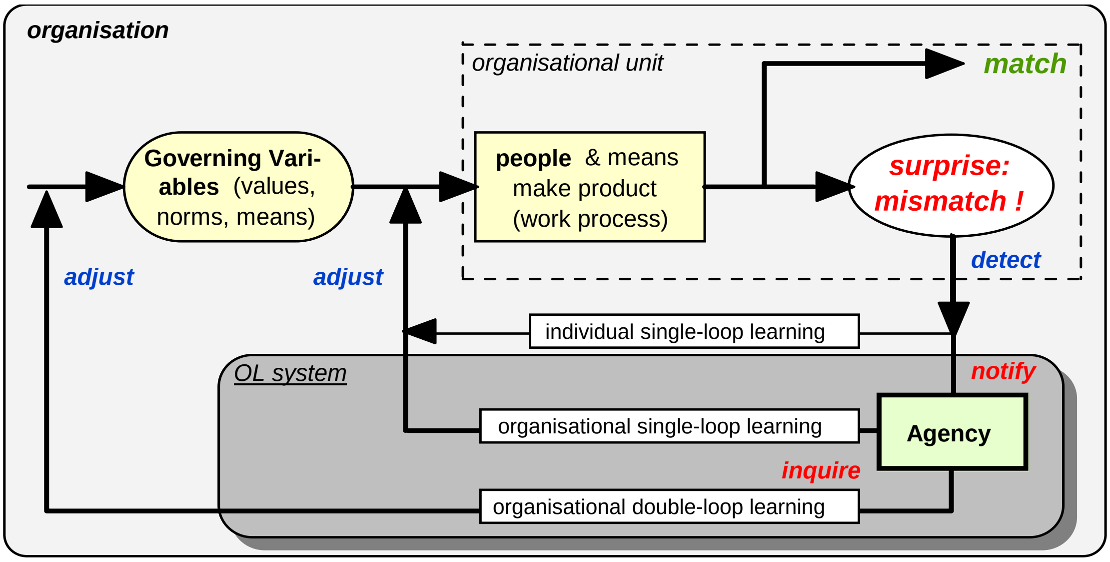

Figure 3a: Single and double loop learning, inspired by Argyris & Schön (Koornneef, 2000).

In summary, four steps are needed to enable an organization to learn:

-A surprise must be initially detected.

-It is then passed to the Learning Agency.

-The Learning Agency launches a further investigation to understand precisely the context in which the surprise has been detected and transmitted, and to draw the most appropriate lessons. The role of this agency is to ensure an appropriate contextualization of the surprises detected.

Lessons from this surprise should be implemented in the organization to be learnt. For this, the Learning Agency categorizes lessons by the level of learning. Single loop learning takes place if the lessons can be limited to the authority of the operational level and practice. In contrast, the Learning Agency may need to refer the lessons to the next level (figure 3a) if the values underlying the practice need to be revised, in which case Koornneef speaks of organizational double loop learning. The Learning Agency fulfils a supporting role in that, through its intermediary role in the analysis and amplification of the surprises detected, it can draw lessons from these surprises and guide them to the appropriate level for decision-making and, can assist in putting in place the necessary actions to resolve the problems identified.

The work of Koornneef was enriched by the System of Organizational Learning (SOL) model:

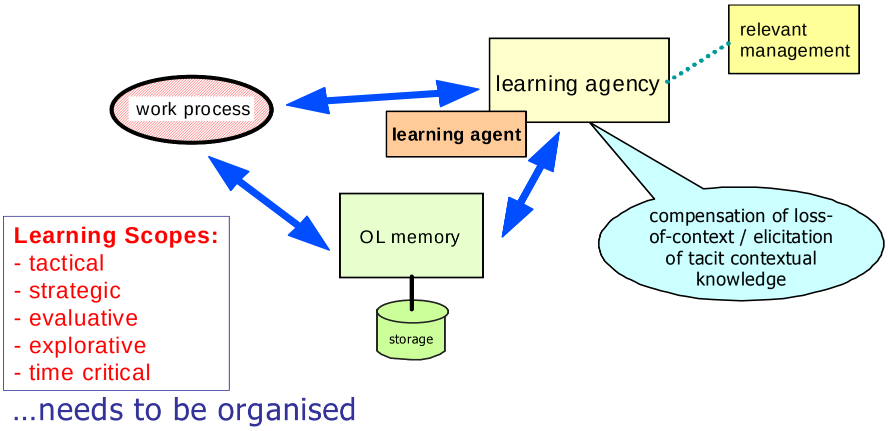

Figure 3b: System of Organizational Learning (Koornneef & al., 2005).

This model expands and complements the first one we presented. It incorporates an organizational memory that will assist the organization to learn from the surprises that can be stored, accessed and reused. In this perspective we can say that organizational learning is not confined to an eternal pattern of detection -transmission - resolution - implementation but that the organizational memory stores the lessons and makes them effectively reusable in a similar situation and with adaptation in a different organization. This model depicts what it is necessary, in functional terms, to make lessons accessible and usable.

2.3.2.2.2 The contribution of formalized organizational learning

Organizational learning is seen as a specific organizational model, requiring the establishment of several functions: notification, transmission and processing of unexpected events or surprises emerging from the operational activity. These functions reify in a sense the basic principles of the communication of information - transmitter, transmission channel and receiver. However they do not develop or explain those principles further, so we return to that issue in section 2.4 of this chapter. Through these functions the learning system adjusts at one or both of two levels: at the first level individual and group practices and at the second level, organizational values and norms. Effective organizational learning must promote an organization in two dimensions:

-Vertical (the two levels of learning),

-A systemic dimension (interdependence of functions of organizational learning).

This model, if implemented, can improve the performance of safety management through the analysis of incidents, whereby the organization can draw lessons geared towards better prevention of accidents. This approach provides a bridge between a relevant organizational model (organizational learning) and action (accident prevention) but also helps to overcome the limitations that seem to characterize Rex. The organizational learning model proposed by Koornneef preserves the context of its data from the Rex through the creation of a Learning Agency. This organizes the learning, including specifying the functions that each element in the system must meet to establish an effective and lasting organizational learning and finally to build an organizational memory which is accessible and usable.

However, we can raise and eventually resolve the following question. The work to implement such a learning system has to be based, according to Tsang (1997), in a national or local company context which is culture specific. To what extent can this 'ideal' model of organizational learning be transferred to other companies, since organizations are unique and specific? We follow Koornneef’s idea by assuming that such a model promotes functions that need to be transferred and translated in the context of the specific organization in order to be appropriated and implemented. The adaptation of this model to a specific organization may be a condition for success.

To summarize, organizational learning is characterized by two aspects. A collective learning is characterized by informal learning (unorganized in the sense of Koornneef), limited to group level, and highlighting the uncertainty regarding the success of learning. A formalized organizational learning is organized in the sense that the elements we have outlined above are present: detection and notification of system events, the establishment of a learning agency, analysis, decision making and implementation of the learning and organizational memory. These are essential before the organization can be labelled as truly learning. Organizational learning should be thought of in terms of a structure but also at the functional level in a systems perspective (where each element is interconnected to allow the organization to function as a learning organization). It is not intended to oppose these two dimensions of learning, but merely to indicate that they are complementary. Organizational learning is formalized in that proactive detection of surprises is encouraged by training the operators to be open to the observation of events considered to constitute operational surprises and to notify the learning agency. This would be for us a way of taking weak signals into account.

Although organizational learning is an important part of our research, we have two reservations about the adequacy or at least the possibility of harnessing this approach. We shall see in the next section, that learning seems difficult (but not impossible) for an organization. We assume that any organization learns in a more and less effective and organized (or formalized) way. However, we believe that organizational learning models are based on a rather ideological view of organizations – that of maintaining their competitiveness in a changing economic environment - but also a view that is idealistic and difficult to implement. Indeed, despite the implementation of tools supposed to support this learning project, organizations come up against numerous obstacles, such as difficulty in learning from experiences and maintaining a corporate memory (described in Koornneef, 2000). These issues will be raised in chapter five.

We will go a step further in the next section by presenting a method for implementing and managing risk control, developed in collaboration between the University of Delft and others in research sponsored by the European Union.

2.3.3 Delft model: method for implementing risk control

So far two important issues have been discussed. First, we have shown the limitations of Rex, which result from a difficulty in drawing effective lessons from events reported and, secondly, the difficulty to integrate into it the weak signals of a potential accident. To overcome these limitations, we have discussed the work of Koornneef (particularly his contribtion to Andriessen & al., 2004) who proposes a formalized (or organized) organizational learning system of event (surprise) reporting in a perspective of learning. The Organizational Learning System is a "prescriptive model" which describes the functions necessary to implement an effective organizational learning but remains limited to the description of functions and relations between these functions to organize learning from these surprises. It needs to be placed in a broader context of risk control.

The Delft model (Hale, 2003 and 2006) is an extended method of risk control. The following section summarizes the main principles of this method. We will see later, its contributions and limitations.

2.3.3.1 Delft model principles and functions

This model is a prescriptive approach which aims to guide organizations in implementing and improving their safety management.

According to Hale (2006), an organization is constantly pushed to the boundaries of a state of good safety, particularly because of production pressures and budgetary restrictions. It must therefore maintain its activity and risks inherent to its activity under control, sufficiently within these boundaries. Hale (2006) defines risk control as a process of prevention and remediation of deviations from an ideal state of safety. To achieve effective risk control, organizations managing a risky activity must implement the following four functions, summarised in figure 4:

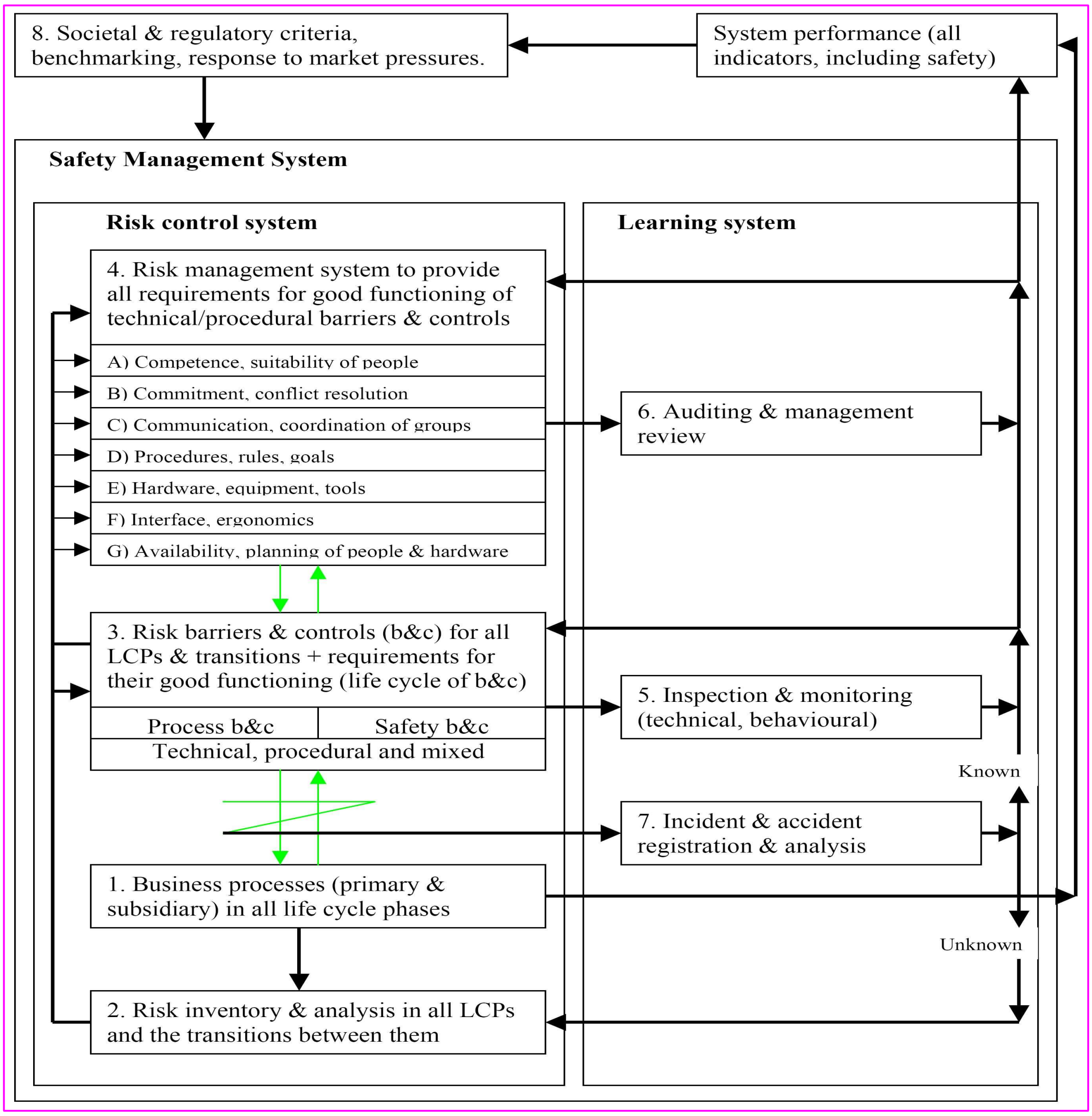

Figure 4: The Delft model, taken from SAMRAIL (Safety Management in Railways) (Hale 2003).

1. **Risk Identification**: An organization must identify all the risks it may face. Use of bowtie figures (Bellamy & al., 2006) shows how these risks emerge from the activity of the site (daily operations, maintenance operations and design)

2. **Building accident scenarios and define control barriers**: A scenario is defined as a sequence which describes the way one type of hazard (corrosion, rapid movement of a vehicle etc)

can escape the control of the organization and cause damage. The organization must be able to build scenarios of all of its generic types of accident and, thus, to identify barriers and safety monitoring to anticipate and prevent or slow these accident sequences.

Scenario building involves the establishment of safety barriers that will prevent the accident sequence previously identified. Barriers, to be effective, must possess all of the following features, either actively or passively - detection of the need to intervene to correct a deviation, diagnosis of what action needs to be taken and action to block the scenario or recover the deviation - in order to keep the overall process inside the "safety envelope" that is to say within the boundaries of critical safety. Barriers and controls may be technical or procedural or both.

The effectiveness of safety barriers is measured and controlled throughout their life cycle - design, construction, operation, maintenance and modification. It is the responsibility of safety management to determine the resources needed to maintain the functioning of these barriers throughout their life cycle. The advantage of this model lies in the fact that the effectiveness of barriers depends strongly on "*design management, daily operations and maintenance …. that determine how these barriers are designed, installed, used, followed and improved* "(Hale, 2003, p. 19). This condition implies that any inherent defect in the activity of the organization may affect risk control.

3. **Resources and controls**: It is the responsibility of safety management to provide resources necessary to effectively operate the barriers. This process of provision is modeled in the Delft approach as "delivery systems", which include: actors' skills and competence, commitment to make safety a priority, communication and coordination, procedures and rules, equipment, interfaces, and availability of operators and equipment. Resources therefore encourage the organization to provide the necessary means for effective safety management and its monitoring and control measures.

4. Learning: Review and improve safety management. Many activities contribute to learning. Inspection, firstly, is responsible for monitoring of the equipment and behavior that are the barriers to risk. Audit systems then check that the management system provides the resources necessary for the proper functioning of barriers. Finally, accident analyses (or Rex) not only analyze the causes of an event but also improves the Rex process if it is considered as ineffective (partially or completely).

2.3.3.2 Delft model contributions

The Delft model enables a proactive approach to managing risks: risks are anticipated by predicting and observing indicators of (potential) deviations and the provision of barrier controls and correction. These indicators are built on the basis of observation of recurrent and hidden information connected with the accident scenarios modeled in the framework of this method. It also allows the organization to set up organizational double-loop learning (in the sense of Argyris & Schön), that is to say a constant review and improvement of safety management through its proactive monitoring at organizational level (norms and values). Although prescriptive, this model features a constant dynamic between functions of system safety management, tasks necessary to maintain risk control and a constantly reassessed organizational learning.

This model contributes to the definition and integration of weak signals of an accident. They are considered here as indicators alerting to a loss of control of safety well before the accident sequence (during the incubation period), at an organizational level (failures of technical and organizational barriers).

2.3.3.3 Limitations of the model

The Delft model is a prescriptive, functional approach. First, it guides organizations in the implementation of functions and shows how these should be put in place. It does not specify the characteristics of the organizational structure, history, culture - or the obstacles that the organization can meet in the application of this model. So we need to ask: how people implement such a prescriptive model? Are there any prerequisites guaranteeing that this model is really applicable?

Second, although the Delft model provides a new “brick” to build the definition of weak signals - indicators of loss of control of risks for which control barriers and correction are designed upstream of the critical event or indicators that a new and unexpected scenario for loss of control is credible - this study does not deepen the way these indicators are to be recognized or transmitted through the safety management system (what communication channels are used?). Because it does not clarify this particular matter, specifically the organizational interactions involved in the communication system and the interrelations between individuals, we lack material on the nature of this information and the criteria by which they are detected and transferred into the system management information.

2.3.4 Conclusion

The first bodies of literature showed, as we stated in the general introduction, that accident analyses enabled us to raise the issue of weak signals. Rex, defined as a process of reporting and analysis of events, seems to be limited to the analysis of significant events and largely limited to the technical dimension. Thus, we showed, as we proposed in the general introduction, that Rex failed in two of its objectives: to detect weak signals (because too often reactive) and to facilitate learning. Rex, in this perspective, does not appear currently as an effective way to tackle the issue of weak signals.

It is clear that Rex may enable a proactive organizational learning when it is both organized and included in a comprehensive approach to risk management. This would favour the identification of indicators of loss of risk control, and prevention and correction by the combination of the available resources and an organizational learning system which is explicitly defined and constantly revised and improved. In this perspective, the Delft model provides new insights to the issue of weak signals.

However, we pointed, throughout the presentation of these models, to a lack of concern for the nature, characteristics and specificities of weak signals. Next section is meant to develop our first hypothesis (see general introduction, section 1.6) by raising the following questions: what are the definition and nature of weak signals? What are the factors that make these signals difficult to detect and treat? We turn to this in part 2.4.

2.4 Weak signals sense-making

The third and final part of the literature review aims to explain more precisely the factors inhibiting or promoting the treatment of information on risks in the management system. To guide the reader, here is a synthesis of the logic that we propose:

-Definition of weak signals:

We will return in the first place to the specificity of weak signals and define them as information which is difficult to discern.

-Transmission of weak signals in communication channels:

Because of this difficulty, sources of information who are potential transmitters in communication channels, encounter difficulties in extracting weak signals from background noise and transmitting them to recipients for two main reasons. The first one is related to the fragmented organizational structure that complicates professional relations, both in the sharing and exchange of information. Second, frameworks for interpreting information can be characterized by their rigidity which blocks the transmission of weak signals. Filtered out and not interpreted as information concerning potential threats to safety, weak signals can remain latent and build up in a period of incubation.

-Making sense of weak signals:

To understand in more detail weak signal processing requires firstly a review of the coding and decoding system in the communication channels, and, secondly, the need to create and stabilize a new method to take into account this specific information.

-Promoting organizational learning:

Weak signals can be a vehicle for learning to the extent that they allow questioning at an individual and collective level of the process of detection, selection, transmission and processing of safety information. Weak signal processing involves a double movement:

- A process of review of the interpretive frameworks
- A stabilization of the new interpretive frameworks

Stabilization of these new interpretive frameworks is considered in this research as a permanent change in the way of looking at risks in a changing business, which should become a daily routine for organizations managing a risky business. We adopt from the Delft model also the idea that this permanency of the paradigm shift does not mean a static SMS. That system needs to be constantly re-examining and re-inventing itself.

2.4.1 Weak signals: specific information and theoretical innovations

2.4.1.1 Weak signals and 'strategic intelligence': information in new perspectives

Strategic intelligence[13] (Ansoff & McDonnell 1990, Caron-Fasan 2001, Lesca & Blanco 2002), has defined weak signals according to two aspects: their nature and their usefulness.

2.4.1.1.1 The specificity of weak signals

Mével (2004) characterized a weak signal as "*More qualitative than quantitative, uncertain, fragmented and ambiguous*" (pp. 20-21). He said: "Weak signals are partial and fragmentary information provided by the environment, possibly in parallel with strong signals, which carry a specific order, and recognized as such by the organization after appropriate treatment" (Mevel, 2006, p. 3). Blanco & Lesca (2002) add the following components in the definition. Weak signals are, or have:

-Low visibility
-Ambiguous, non-obvious
-Little or no familiarity
-Apparently low value
-Low apparent relevance and reliability
-Low palpability

[13] This is a translation of 'veille stratégique' which is a field of study and practice in France covering the process of looking out for trends and information relevant to the strategic decisions of organizations. Its roots lie in the search for intelligence for economic decisions, but it has been adapted more recently to the safety field

Finally, Caron-Fasan (2001) also notes these features while adding that the weak signals are information subject to multiple interpretations. We see through these definitions, weak signals have a specific nature. But why focus on this issue?

2.4.1.1.2. The usefulness of weak signals

The usefulness of weak signals is stated as one of their main characteristics: weak signals have the power of anticipation. Ansoff & McDonnell (1990) propose to consider weak signals as "*imprecise early indications about impending, impactful events*" (Ansoff & McDonnell, 1990, p. 20-21). Mével (2006) writes: "*Weak signals are key elements of the information process by which the company listens to its proactive environment to create open windows of opportunities and reduce uncertainty and its risks* "(p. 4). Lesca (2004) cited in Mével (2006) points out: "*The signals are anticipatory strategic information from the business intelligence system implemented by the organization*" (p. 4).

Weak signals are also considered as strategic information. Julien & al. (2002) refer to the work of Granovetter (1973)[14] who identified two types of networks in economic sociology: a network of weak ties and a network of strong ties. From a quantitative survey of individuals seeking a job in Boston, Granovetter studied a strategy relying on networks of weak ties at the expense of strong-link networks such as intra-family. Colonomos (1995) writes: "*This network theory identifies innovative capacities of individuals in defining their path to social circles outside of the first ones which expanded.*" Julien & al. (2002) transposed the concept of weak networks to the study of technological innovation in small companies in the area of transportation equipment. Networks of strong ties are defined by their interrelationships between people who trust each other, within habitual professional partnerships. Weak networks consist of less frequent or close relationships. These studies suggest the idea that weak signals emerge from less formal networks, requiring from individuals more sensibility and observation to capture the signals, but also to motivate those individuals to pursue individual and collective strategies of innovation in response to them. Weak networks are not used to the detriment of strong or more formal networks. They are exploited for their extra potential for innovation.

To summarize, weak signals seem to be defined according to two characteristics: they are by nature fragmentary and transmit an ambiguous message, but are of strategic interest; they would enable an organization to anticipate events. Ambivalence lies at the heart of the issue of weak signals. What happens in the field of risk?

[14] This is only a quotation. This reference does not appear in the bibliography.

2.4.1.2 Weak signals in the safety management domain

Vaughan's work (1996) provides a central contribution to our research. Her extensive work on the Challenger shuttle accident has led her to categorize three types of signals:

-Mixed signals: "*signals of potential danger followed by signals that indicated that all was well, reinforcing the belief in acceptable risk*".

-Routine signals: "*frequent events, even if known to be inherently serious, lose some of their seriousness as similar events occur in sequence*".

-Weak signals: "*information that is so ambiguous that the threat to flight safety was not clear*".

To Vaughan (1996), a weak signal transmits ambiguous information in the sense that the link between this signal and the safety threat is neither direct nor obvious. It is a signal that, after analysis, appears so unlikely that it has little chance of a repeat (Vaughan in Bourrier, 2001). Thus, the low temperatures recorded on the day of the Challenger shuttle launch that damaged O-rings were so exceptional that they were not considered as a proven threat to flight safety.

Pariès & Bieder (2006) define weak signals as any event transmitting information related to risk so subtly and indirectly that they escape perceptions usually constructed by individuals and organizations. A signal will be strong or weak according to the representations of risk developed within an organization. Here, the specificity of weak signals is the uncertainty about the phenomenon they provide information on; the information they convey does not constitute a clear and direct threat to safety.

Given these definitions, we consider weak signals as information which could anticipate an event but remains difficult to understand and interpret because of their ambiguous, uncertain and fragmentary characteristics. Our research on weak signals cannot, however, be satisfied to stop at these definitions, even though we recognize them as vital contributions. It must build on them and take them further. To do this, we develop next the notion of signal as referred to more dynamically in communication theory. What are weak signals in this theory? Why do they persist?

2.4.2 Communication theory: transmission and receipt of a signal

2.4.2.1. What is communication?

Communication includes a variety of theoretical and applied fields: physics, mathematics, semiotics, psychology, sociology, etc. The study of signals fits into the theory of communication where a signal transmits a message between a sender and a receiver. The purpose of this section is to refer to factors that may confuse or weaken the impact of this message during the transmission of a signal. To do this, we go back to the principles of communication.

In generic terms, communication is “*a means of sharing of elements or behaviour, or modes of life, by the existence of sets of rules or sign usage*“ (Cherry, 1982, p. 6). More exactly, Cherry says that communication is a sharing act: “*We can communicate with one another in this world or outside it, only in as much as we can share sign-usage”* (p. 30).

Communication consists of several components that we propose to categorize under two headings as follows:

-Structure: transmitter (source), transmission channel and receiver,

-Content: the signal detected by the source, the information and the message.

The article entitled "Sociology of Communication" taken from Encyclopedia Universalis lays the groundwork for a communication framework. Its authors point out that communication refers to both the passage of a message between two points and the transmission of the meaning of the message. "*Each message can then be defined as a combination of signs referring to a meaning according to an encoding model*” (Vol. 4, p. 765). Communication assumes the existence of a source and a transmitter which encodes in a message the meaning of the signals emerging from the source. The message is transmitted through a material or immaterial channel (transmission channel) to a receiver who decodes the message (after some losses due to interference or background noise). The following sections discuss these elements in more detail.

2.4.2.2 Signal detection and emission: background noise

2.4.2.2.1 Weak signals in physics and statistics

If we return to the first stage of communication (detection by the source), it is relevant to refer to the concept of background noise. Brindejonc & Llory (2005) suggest that a signal refers to a change of state: "*The state of a system is defined by a configuration identified as stable on a given time scale in a given environment. ….. Events are physical facts localized in time and space. A particular event can always be defined as the transition between two states of a given system. The signal is a physical phenomenon transmitting information. It is the observable trace of the event* "(p. 30).

Extracting weak signals from background noise is essential. Mével asserts that "*weak signals are similar to background noise whose value is seen only after appropriate treatment*" (2006, p. 3). The issue of weak signals for the same author lies in decoding and decryption of signals emitted by the environment of an organization (or in our case also within the organization). Mével concludes by writing: "*An organization is sick when it has progressively and permanently become insensitive to noise and regulatory signals that come from both its internal and external environment”* (Mével, 2006, p. 5).

In physics, the concept of filtering acts to reduce the amount of background noise. This technique helps the processing of detecting weak signals, by extracting weak signals from background noise so as to consider them as relevant vectors transmitting information on a change of state. Two methods of extraction can then be considered: reducing the intensity of the background noise to uncover the weak signals, or amplifying the weak signals so that they stand out better from the (constant) background noise.

Finally, in statistical terms, signals can be selected according to their probability or frequency of use Cherry (1982). The goal of a statistical study of signals is less the content of information than the frequency or pattern of signals coming from a given source. We are looking for the probability of occurrence of a signal. In this perspective, the rarity of a signal refers to a low frequency of occurrence. Amplifying weak signals requires therefore two things: extraction from the background noise, and identification of those with the highest frequency or recognizable pattern.

2.4.2.2.2 Weak signals in the safety management domain

If we apply these ideas to the field of information management related to safety, weak signal detection refers to the issue of detecting and selecting relevant information from data accumulated in information systems and during workforce audits and inspections. In other words, an organization (and individuals) has to establish criteria for the detection and selection of weak signals. A compromise has to be found between a high threshold of information filtering, which carries with it a risk of losing a significant amount of potentially relevant information, and a low threshold which may retain more information, but will include more false alarms. This analysis raises the following question: to what extent can an organization identify valuable repetitive and one-off signals? According to what criteria will signals be detected and processed?

These criteria are obviously not so simple to set up. It takes a more complex definition when we apply that idea in a broader context, such as the transmission of information within an organization

2.4.2.3 Transmission and reception of information: an active process

We assume that weak signals are detected from background noise, which is not likely to be constant, and from other relevant signals from which we have to differentiate our weak signals. The challenge is to recognize these potentially relevant informational signals, i.e. signals conveying information about or indications of a phenomenon to help us understand and anticipate, in our case, risks of accidents.

2.4.2.3.1 Transmission of relevant information on an impending accident

Mével (2004) distinguishes three perspectives in his study of weak signals: the statistical, symbolic and semantic perspective. The semantic perspective is appropriate for our research because, as suggested by Mével, this approach is" *based on the study of language units and signals which transmit information that is exchanged between a transmitter and receiver*" (p. 35). He goes on: "*The interest of weak signals lies in its descriptive potential and its potential for individual and organizational learning*" (Argyris, 1976, p. 35).

Cherry (1982) said in turn that the theory of communication refers to the evaluation of the information content of a signal, that is to say the content of a signal based on the potential information that it transmits. This definition is crucial as he considers communication as the transmission of signals having "*At least some surprise value, some degree of unexpectedness, or it is a waste of time to transmit them*" (p. 14). A signal transmits, in this sense, a message "*of an informational nature*" to a recipient. This message is encoded by a coding system "*a set of sign-types*" which must be specified and be the same for the sender and recipient and, finally, it is the responsibility of the transmitter to select signs, create a message and send it through a communication channel to the recipient. The latter, receiving the signal, decodes the message with the current decoding system. With this achieved, the message has been transmitted and received. See figure 5, based on Adler & al (1983).

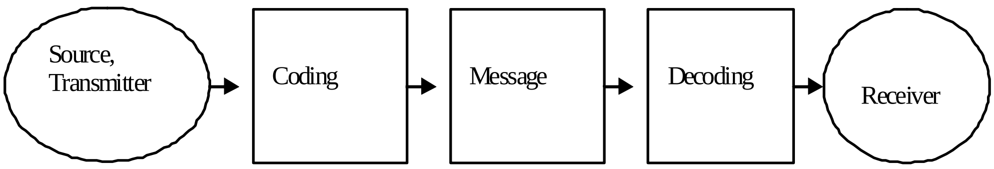

Figure 5: Model of linear communication based on Adler and al. (1983).

Based on this work and figure 5, we define a signal as a pre-coded message sent to a recipient who, in turn, decodes the message. Signals, designed to deliver a message, are transmitted from the signal source, via the signal transmitter to the recipient to produce a set of data (objective) that can be used. However, we believe that these data, to be used, should make sense for individuals. Mével & Apgral (2006) assert that information is extracted from data, through a process of sense making. To be turned into information, data must go through a communication structure in which analysis categories will make sense to these data for individuals composing the organization. We deal with this issue in the next section.

2.4.2.3.2 Transmission of information on safety threats

To Turner & Pidgeon (1997), transmission of information depends both on the presence of a transmitter and a receiver and secondly on the existence of appropriate categories of analysis of the receiver. Both sociologists are particularly interested in information transmitting a message of threat or warning within a high-risk organization. Information is, in their view, assessed by individuals according to the changes they produce in their knowledge of risk uncertainty. The uncertainty decreases when information can be evaluated based on other information known or experienced by the receiver which can be mobilized to process the new information. The receiver's knowledge about the transmitted information is therefore crucial. Turner & Pidgeon (1997) state that accidents can, nevertheless, be surprises or unexpected events. Thus, uncertainty related to the circumstances and consequences of such an accident is high; an accident may disrupt analysis and interpretation frameworks, and knowledge of this event may be revealed to be insufficient or unavailable. Turner & Pidgeon (1997) defined the following model of communication in a closed system (Figure 6):

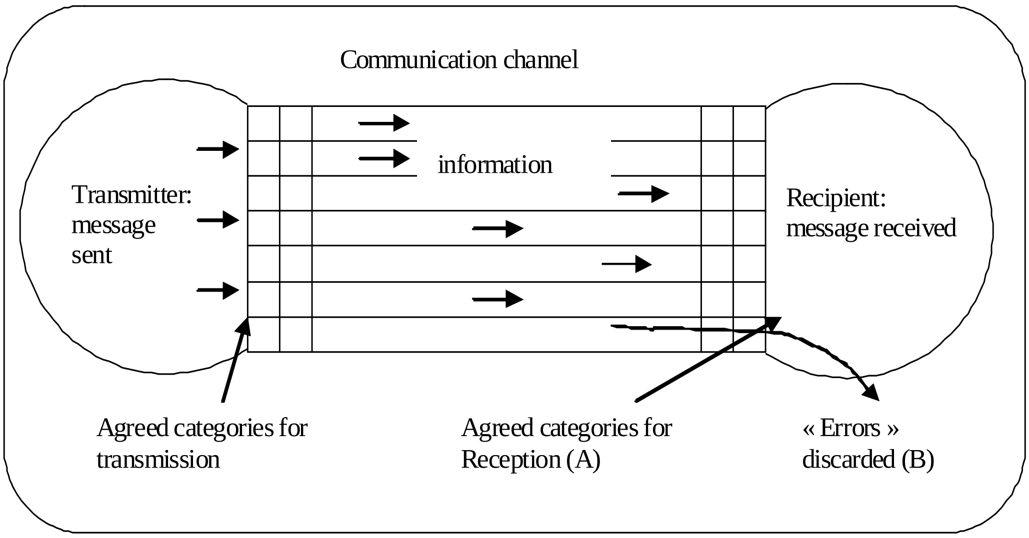

Figure 6: Closed communication scheme (Turner & Pidgeon, 1997).

In this closed communication scheme, if transmitted information falls into the "good" category, then information is received (A); however, if information falls outside this category, it will be considered as an error and any chance of interpretation will be rejected (B). Only information calibrated to be detected and transmitted by the coding system (or interpretive frames) in operation will be taken into account in the communication scheme.

Bourrier & Laroche (2000) explain the possibility of drift in the processing of information, by the tendency of some organizations to ignore signals of risks or to misinterpret them. This tendency is rooted in the existence of filters (cognitive, collective, and cultural) that may increasingly blind organizations faced with risk, coupled with a tendency to organizational drift, that is to say, an accumulation of practices deviating from good standards but not considered as sources of risk.

We hypothesize that organizational factors block the ability of individuals to identify, select and transmit information such as weak signals. These factors, characterized by their rigidity, would block the capacity for observation and processing of new or dissonant information. The more analysis frames/categories are rigid, the more it will be difficult for the organization to integrate in the analysis weak signals defined as uncertain, ambiguous and fragmentary information falling outside those rigid categories. We turn now to the questions: what are the characteristics of these factors and how to identify them?

2.4.3 Weak signals blockers

Weak signals are, according to our definition, fragmentary and uncertain information, but provide a power of anticipation. The difficulty of weak signals lies first in the ability of individuals to capture these signals - by nature hard to discern- and secondly to interpret them as signs of a potential threat to safety. We have shown that signal detection occurs through the extraction of relevant information from background noise. To transmit this information and create knowledge, these signals must indeed allow the transition of information that makes sense for the sender and the receiver. So, weak signals are potentially relevant information whose meaning escapes the scope of the individual's (especially the receiver's) interpretation or understanding.

What produces a weak signal? We hypothesize that several factors weaken their intensity, the power of the message conveyed by that signal, through a filtering process. These factors prevent individuals in the organization from interpreting this information as potential threats to safety. Thus, these warning signs accumulate undetected and contribute to the building of the incubation period. A posteriori, i.e. after the accident or critical event, the link between these signals and the threat to safety becomes clearer. The incubation period, once revealed by the accident analysis, may reveal two phenomena:

-How those weak signals accumulated,

-Where the difficulty of processing lay, upstream of the critical event.

The next section outlines the nature and role of these blocking factors that prevent individuals from detecting and treating information. We will retain Turner & Pidgeon's classification (1997) who outline in particular the following main factors:

-Risk perception,

-Organizational complexity,

-Production pressures.

We hypothesize that these three factors will prove highly relevant in understanding and explaining the difficulties of processing weak signals in the industrial sites where we carried out our case studies.

2.4.3.1 The difficulty in imagining the worst: cognitive perspective

Information may not be understood because of reluctance to apprehend the worst. For Turner & Pidgeon (1997): "*Clearly, when existing danger signs are not perceived, are given low priority, are treated ambiguously or as sources of disagreement, and when they are treated as insignificant for psychological or other reasons, another avenue is provided for the accumulation of events which may combine to lead to disaster*" (p. 87).

The authors focus on the blindness of an organization to the potential emergence of a risk and its severity. This idea corroborates the work of De Geus quoted by Roux-Dufort (2000) who identified four sources of blindness to weak signals:

-Leaders do not see clearly until the crisis has opened their eyes, therefore the solutions are often developed after the fact.

-Leaders only see what they have already experienced

-We see only the elements relevant to the future(s) we have imagined.

-Psychological factors block the acceptance of evidence of risk

Considering "the worst" is challenging and uncomfortable and may lead an organization to ignore some signals transmitting essential information of a risk to come. We have cited the work of Bourrier & Laroche (2000) above, which matches this perspective, as does the notion of normalization of some discrepancies, as defined by Vaughan (1996), which are no longer interpreted as sources of risk.

2.4.3.2 Culture, communication and coordination: organizational perspective

2.4.3.2.1 Organizational culture

Culture can also get the organization to ignore or misinterpret some information alerting to a safety threat. Vaughan (1996, 2001, and 2004) showed that the technical culture of NASA, characterized by the application of formal procedures and confidence in quantitative evidence about statistical events, did not enable some signals to be taken into account, particularly those which are more qualitative, based on lived experience, or even intuition. These are therefore weakened. In the Challenger shuttle accident, the link between low temperature and joint erosion was not interpreted as a potential danger because little hard evidence proved this link. In addition, bureaucracy, characterized by respect for rules and procedures, took a prominent place in the perception and attitudes of managers and engineers. The latter believed that by complying with the rules and procedures they ensured the safety of the shuttle and therefore did not need to be alert for any new and unexpected signals of risk. In this way information is ignored or misinterpreted because of frames of reference (cognitive, cultural and organizational) for analysis that are too rigid.

2.4.3.2.2. Organizational complexity

Information may be not be transmitted due to difficulty in managing information in a complex situation. The more relationships between individuals increase, the more information processing will become difficult, and communication errors can accumulate and build a period of incubation. Turner & Pidgeon (1997) explain that the probability of accumulation of such errors increases when the organization is organized in distinct (sub)cultures. The more complicated tasks are, the more information flows will be important. This structural complexity may lead both to the fragmentation of the organization – separated skills and departments divided into sub-activities within the same organization - and secondly by a fragmentation of information management - sources of information are fragmented within the departments and are difficult to treat uniformly or to integrate together to retrieve more generic messages.

Structural secrecy (Vaughan in Bourrier, 2001) is a common issue in organizations. The division of labour, organizational complexity and geographical dispersion of units limit the ability of individuals to understand each other’s missions:

-Knowledge of individuals about the duties of their colleagues is negligible because of the segmentation and compartmentalization into sub units, which therefore reinforces the sub-division and the scattering of expertise,

-The distance between the work floor and top executives is widening.

The means for exchanging and storing the wealth of information ultimately generate new problems: the more information that is stored the more it becomes difficult to integrate, cross reference and treat it. Analysis of the Challenger shuttle accident case proved that structural secrecy contributed to the normalization of deviance by making the severity of the problem of the O-rings imperceptible to the leadership, preventing them from avoiding the drift in risk perception. In this way organizational structure may affect both information flows and the way of interpreting information, and keep "secret" the information on safety threats (Vaughan, 2004).

The difficulty of managing information in a complex situation is the result of an increased complexity in the organization of work, generating a fragmentation of sources and transmission of information.

2.4.3.3 Production pressures

Vaughan (in Bourrier, 2001) showed that production constraints on the launch of the shuttle Challenger contributed to the process of normalization of deviance. The requirements of production and efficiency had invaded the culture of the organization, thus changing the content of activities, timing and decision making. NASA had to meet very difficult targets with greatly diminished staff resources, training and equipment. Even before the accident, it was expected from NASA that it achieve a high level of performance and establish a competitive program without additional resource allocation. The slogan "faster, better and cheaper" implied less crewed flights and a declining enrolment. The pressures of the environment, especially production pressures, can lead to the treatment of problems related to safety being given second place. This allocation of priorities can have a clear effect on the possibilities and organizational capabilities to detect transmit and process weak signals.

In summary, we have identified three factors blocking the interpretation of information alerting to a potential threat to safety:

-An assessment and perception of risk based on rigid frameworks (rules, beliefs and/or culture), filtering out relevant information despite its informational power,

-A fragmentation of information sources and transmission channels within the organization, which complicate integration, cross-referencing, analysis and therefore interpretation of information.

-Pressures of production preventing the detection and treatment of internal information

Critical events (accidents, disasters) are defined by Turner & Pidgeon (1997) not only as a combination of technical failures but rather from a sociological perspective. The vulnerability of organizations at risk remains hidden or unexplained by the persistence of a social process that tends to minimize risk assessment.

We will now try to show to what extent the identification of these factors is relevant in understanding the issue of weak signals.

2.4.4 Revision and stabilization of the frameworks for treating weak signals

We have defined a signal as a message transmitting pre-encoded information. This signal attracts the attention of the recipient if it has some degree of unexpectedness, surprise or novelty. However, through the chain of communication, organizational factors can weaken the impact of these messages. Signals, ignored or misinterpreted, persist during an incubation period. According to Pidgeon & O'Leary (2000) this problem is rooted in a culture of safety that is at odds with the actual risks of the activity, a dissonance (Turner & Pidgeon, 1997) between perceived reality and the reality in which the organization actually operates.

The issue of weak signals requires for its solution a change which is close to a revolution. It needs a cognitive and organizational revision (Turner & Pidgeon talk about cultural adjustment) of the way of considering weak signals in the management information related to safety. The need to revise the existing frameworks for interpretation and analysis would be a proper perspective to respond to the issue of weak signals.

2.4.4.1 Making sense of weak signals: a creative process

Roux-Dufort's work (2000) sheds further light on understanding the notion of signals. Semiotics distinguishes two components in a signal: the signifier and the signified. The signifier is a code that corresponds to a given signified. In other words, all meaning refers to a signified and makes sense in the context in which it is observed. How is it possible to see that a signal provides information on a specific phenomenon? Roux-Dufort (2000) writes: "*A weak signal is a signifier to which it is difficult to associate a signified because it fits outside any coding scheme and generates a multitude of different meanings"*. The issue of weak signals requires us to be able to assign a meaning to these signals. According to Pariès & Biederman (2006) little attention has been given to the process of discernment, that is to say, the ability to detect a signal and be surprised by it. We hypothesize, as does Roux-Dufort (2000) that weak signals suffer from lack of a valid frame of analysis which would enable them to be taken into account. What is the key to interpret those signals and implement actions to integrate them into the system of information management related to safety? As suggested by Roux-Dufort (2000), weak signals are not sufficient in themselves to inform about a problem or a dangerous situation. To grasp their meaning, the information must be decoded, transformed into knowledge, skill and decision. Caron-Fasan (2001) proposes a suitable approach for the exploitation of weak signals, namely the mobilization of a process of creative construction of meaning.

2.4.4.1.1 Identifying the rigidity of analysis frames

To consider and interpret signals with information potential to generate a surprise Bourrier & Laroche (2000) and Roux-Dufort (2000) recommend the adjustment of cognitive frames mobilized in the process of interpreting information. If signals are treated in a closed communication scheme (figure 6), their message might be ignored. They remain hidden in the organizational system during the period of incubation. These "unexpected events", as Turner & Pidgeon (1997) write, need to be interpreted in an open communication system, a system that is responsive to surprise, allowing in its structure and characteristics, the possibility of challenging frames of analysis which are too rigid. We consider weak signals as information requiring an ability to respond to the unexpected through a mental process that can be called intelligence (Östberg, 2006).

Whenever individuals want to communicate in an innovative way - to receive and transmit information such as "surprises" or "disjunctures" - the frames of analysis should be revised so that they can take this information into account in a satisfactory manner (Turner & Pidgeon (1997). This is because information whose meaning does not fit in the existing frames of analysis is filtered out before it can become a source of surprise and therefore increase the uncertainty of individuals, prompting action. This research is particularly interested in disasters - unexpected and unfavourable events - characterized by their high degree of uncertainty because no frame of reference is immediately valid to take them into account before they happen. They therefore cause a considerable disruption, accompanied by a discontinuity in the process of information processing and uncertainty reducing. An accident is, in this perspective, an unexpected event less in its gravity than in the degree of uncertainty it entails. However, by then it is too late; the harm has been done. What we want is for the currently weak signals prior to the accident to trigger surprise and action before the disaster

2.4.4.1.2 Open frames of analysis

To cope with this uncertainty and reduce the risk of filtering out warning signals, adjustments in the traditional closed model of communication are necessary. Figure 7 summarizes the process of revision of interpretive frames needed to transmit information defined as a "surprise".

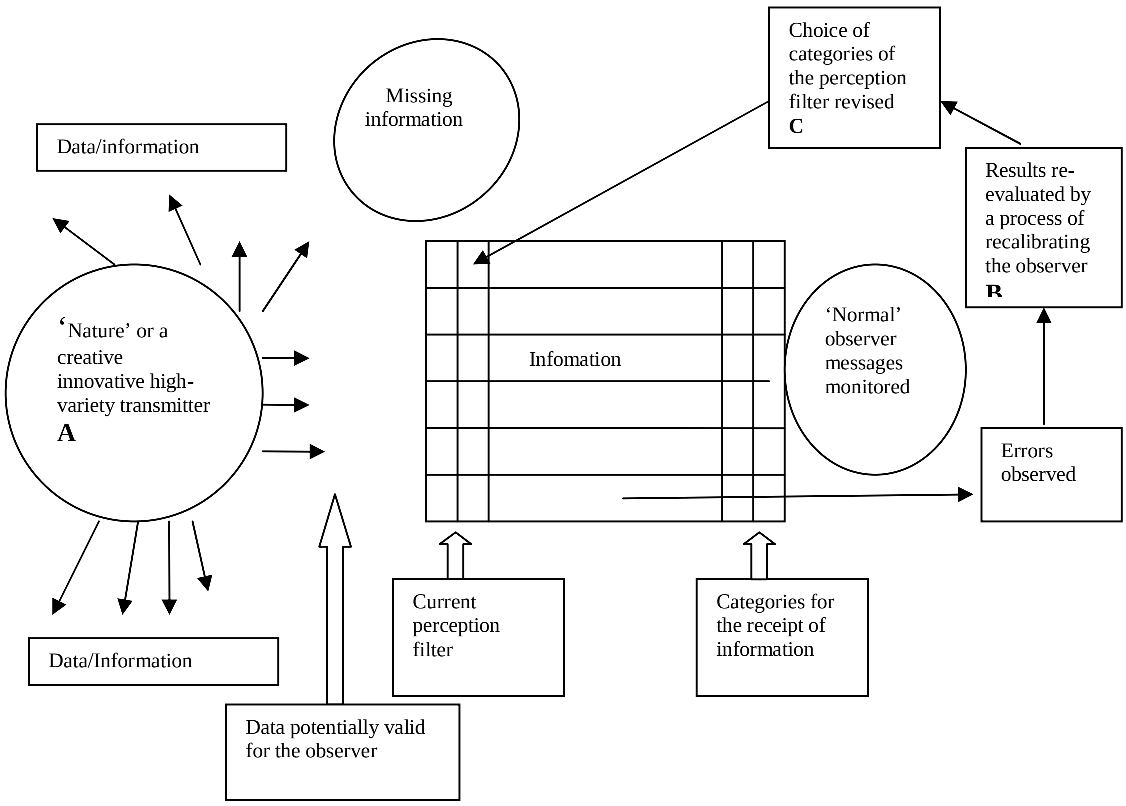

Figure 7: Schematic representation of a communication and observation framework (Turner & Pidgeon, 1997).

Figure 7 goes beyond the limited components of the closed model of communication given in figure 6). These additions involve three stages which are summarized as follows:

-Data (of a different nature) identified through awareness of environmental or internal changes by a more observant and open-minded observer/source (A),

-An additional loop taking into account errors, previously rejected, which are now received and reconsidered (B),

-Reviewing and changing the filters and frames of analysis in order to no longer filter but to incorporate new information considered as relevant (C).

The shift from a closed system of communication to an open communication system, according to Cherry (1982) provides, in summary, the possibility to take account of new information by reviewing the frames of analysis that shape the communication patterns and thus consider the emergence of new risks. In this sense it opens up single loop learning to become organizational double loop learning.

According to Turner & Pidgeon (1997), accidents are considered to break down accepted beliefs about risk. They highlight the need to revise the interpretive frames of information circulating within an organization in order to take into account those generating a surprise, so that these accepted beliefs about risk can change without the accident needing to occur. But this approach, fundamental we agree, is not enough. Other studies have made contributions to broader perspectives. We will show in the next section that weak signals require not only the opening up of frames of interpretation of information but also a process of sense-making of unforeseen events, at the individual and collective levels.

2.4.4.2 Revision of analysis frames

2.4.4.2.1 The recognition of organizational ignorance …

In the light of the definitions we have provided on weak signals, difficulties in their capture and the need to give them meaning, we believe that the notion of sense making seems relevant in our research.

Macrae (2007) developed the idea of the recognition of "organizational ignorance". To identify an upstream risk, safety investigators (the population he studied in his research) need to recognize their ignorance, that is to say, the possession of limited or even false information about incidents which have occurred in their organization. They have to admit, therefore, that risk areas are areas where their knowledge is imperfect or lacking. Assessing risk requires, therefore, identifying those areas of ignorance and thus calling into question and revising the frameworks for information interpretation related to risk management.

The author stresses a very interesting ambivalence: on the one hand, the investigators must acknowledge the limitations of their knowledge of the operational activity and incidents and accept the existence of (unknown) risks; on the other hand, they must recognize the risks as errors or failures of the organization. To overcome this failure, they need to put in place "interpretive vigilance" (Macrae, 2007). This is step A in figure 7. This means that the investigators must develop a high degree of sensitivity to weak signals alerting to potential problems, identifying gaps and deficiencies in their knowledge of their business and operational risks inherent in it.

2.4.4.2.2… in the revision of interpretive frameworks

Macrae’s study (op. cit.) provides some clues as to how this can be tackled. Disruptions caused by incidents generate, for investigators, a reconsideration of not only their own knowledge, but also the quality of data on critical events they must analyze. These challenges are opportunities to question beliefs and models of interpretation, and it is the very fact that they do not conform to current beliefs that must trigger work to make the reconsideration. Macrae (op. cit.) identified four steps in the sense-making process:

1. Linking of data on critical events with a wider frame of reference - data on major accidents in the past, for example.

2. Identification of common factors or the occurrence of similar events which the investigators had not yet considered. These repetitions indicate that the methods of risk analysis have remained inadequate. This process, says the author, is based on an interpretive process more than a statistical method.

3. Awareness of their inadequate knowledge to understand and resolve the situation. This discrepancy alarms investigators, indicating that new data are needed for an understanding.

4. Questioning the relevance of their operational knowledge, when an event presents new facets of errors. Recognizing these weaknesses is an indicator for the investigators, of their degree of ignorance and therefore an opportunity to revise the methods of analysis previously accepted.

Sense-making, at least as applied in this study, implies a twofold step for the investigators:

-The search for similarities, or common factors between data by establishing a data link between them,

-An extension to a wider frame of reference, to give them “sense”.

Macrae (in the same study) therefore defines sense making as a process implemented by individuals to understand ambiguous situations they encounter in organizing and interpreting questionable data and in making sense of confusing situations. It is put in place when those same individuals detect signals and connect them with a broader framework, allowing them both to give meaning to these signals and the situation encountered and to guide their actions. According to Weick (in Macrae, 2007), these anomalies can be detected by people sensitive to unexpected deviations[15]. They set out to expand their knowledge of what has been detected and to solve the problem as fast as possible.

The fragmentary and uncertain nature of weak signals requires putting them into the context of a wider frame of reference in place and hence to interpret this surprise thanks to the new frameworks of analysis. Assimilation and differentiation are not paradoxical notions but two fundamental steps which are both necessary to make sense of weak signals. To deal with weak signals, Brindejonc & Llory (2005) also identify in the first instance repetitions, hidden similarities and making cross-references to develop databases of potential risks. In the second place, they suggest mobilizing non-formal or informal methods, which seek to capture events that are beyond any systematic and formal methods and which leave room for imagination.

Weak signals constitute information whose meaning may be uncovered through two steps:

[15] This idea refers to Koornneef’s notion of learning agency. Weak signals may be processed by a suitable learning agency devoted to conducting complementary inquiries on operational surprises.

-Locate fragmented data and information about repetitions or patterns related to safety,

-Identify their relevance to a specific context: safety management (and specifically the risk of accident).

In sum, many weak signals arise out of existing or potential data. Their relevance is revealed when the organization works to recognize, detect and operationalize signals into data. As we stated in section 2.4.2.3.1, information is a process of sense-making about data. Using and experiencing this information, leads to success in detecting weak signals, their treatment and putting in place actions, all of which may promote knowledge on the risks inherent to the business run by the organization that can be shared internally (and externally).

2.4.4.3 Stabilization of analysis frames: building organizational reliability

A self-designing organization is an organization that can treat and digest a large number of events, pressures and surprises. In this perspective, Bourrier (2000) says that a self-designing organization provides to its employees the explicit authority and necessary resources for the continued adjustment of procedures and operating rules to deal correctly with unforeseen situations. A self-designing organization would have the ability to constantly reconsider the basis on which it operates. It integrates a pattern of open communication and the two steps necessary for the attribution of meaning of weak signals (see section 2.4.4.2.2).

However, how can an organization maintain reliability if it is characterized by a constantly changing business in a turbulent or threatening environment? Weick, Sutcliffe & Obstfeld (2008) explain that reliability depends, among other things, on the stability of the cognitive models used to maintain such a level of reliability. Faced with unexpected events, risk assessment models have to be revised, which is possible through the mobilization of stable processes of revision (such as the process of sense-making). These are stable meta-processes, which achieve constant reconsideration of the underlying processes. Reliability therefore depends more on the ability of individuals to adapt their cognition and action, than on defining specific methods of reliability management.

2.4.4.3.1 Stabilization of the process of managing surprises: a resilient organization

Hollnagel & al. (2006) define resilience as the ability of a system to anticipate and adapt to errors and potential surprises. Resilience Engineering in safety management is an approach that allows organizations to successfully face a complex situation. The authors write: "*A resilient organization treats safety as a core value, not a commodity that can be counted. Indeed, safety shows itself only by the events that do not happen! Rather than view past success as reason to ramp down investments, such organizations continue to invest in anticipating the changing potential for failure* *because they appreciate that their knowledge of the gaps is imperfect and that their environment constantly changes. One measure of resilience is therefore the ability to create foresight - to anticipate the changing shape of risk, before failure and harm occurs [Woods, 2005])*" (Hollnagel & al., 2006, p. 6).

Resilience engineering puts safety management in a proactive perspective. The essence of a resilient organization according to Hollnagel (Hollnagel & al., 2006) is the intrinsic ability of an organization to maintain or regain a dynamically stable state and to continue operations after a change such as an accident or continued stress. He makes clear: "*The earlier the adjustment is made, the smaller the resulting adjustments are likely to be*" (Hollnagel & al., 2006, p. 16). The advantage of a proactive perspective is that it reduces the impact or adverse effect of deviations on organizational stability. The resilience engineering approach is therefore made up of methods and principles protecting the organization against the instability generated by surprises or unexpected situations.

These studies provide important contributions to the proactive management of risks of accidents. They can be defined by a twofold approach. On the one hand, attention to changes, failures, crises, threats from a changing environment. People in these organizations pay more attention to these disruptions and do so as early as possible, in other words, during normal operation. The attention to new information leads us to hypothesize that this type of organization will incorporate and take into account information such as weak signals. On the other hand, it requires stability - in the sense of being able to understand these failures to maintain reliability through the organizational mobilization of stable and stabilized cognitive processes of sense-making. This approach can therefore anticipate surprises and by extension manage the surprises that high risk organizations may face. To Ansoff & McDonnell (1990), monitoring and organizational flexibility are the key words for an effective detection and response to weak signals.

Two other dimensions are important to us: a cognitive and collective dimension dedicated to building an organizational "meaning" or "intent" to anticipate and correct or learn from errors and surprises; and an organizational or policy dimension which embraces and legitimizes this approach to sense-making.

The idea underlying this work, we believe, is to make management of the unexpected a way of life for organizations, so that they are always ready for surprises. They need to make of the two steps of revision and stabilization a process of anticipation and management of the unexpected which is a daily, or at least a periodic, routine activity.

2.4.4.3.2 Negotiating the social order: the organizational level

Finally, to conclude our remarks on the two steps of the revision and stabilization process, we would like to refer to the work of Strauss (1992). He showed the extent to which individuals in a work group put efforts in to “maintain sense”, in the unity of their activity with that of the organization they make up.

The reconstruction caused by a disjuncture/failure, is not only realized at a cognitive and individual level. Indeed, we believe that the whole organization is involved in (re)negotiating a social order at the collective level. Strauss (1992) writes: *"Any change that challenges this order (in his case a hospital) – whether normal, such as the arrival of a new team member or disrupting – a contract broken – or something exceptional such as the introduction of a new technology or a new theory -, any change will require a renegotiation or re-evaluation which will result in changes in the organization. We must insist on this point: a new order and not the restoration of an old order, the readjustment of a previous balance* “(p. 108).

Strauss (1992) says very clearly that failure or change within an organization cannot be ignored. If we take this proposal into account, and with all due caution, we assume that each case of failing to respond to weak signals generates failure. This must be taken into account not only in the tools for the management of signals – which, as we will see in the case studies, have limitations - but also through the individual and collective capacity to challenge ones own interpretive frames[16].

High Reliability Organization (HRO) theory proposes to deal with surprises by mobilizing or rather stabilizing the frameworks for interpreting information previously reviewed and adjusted. This mechanism has also been described by Strauss (1992) at the organizational level. He showed that in an organizational context characterized by change (see definition above) in which actors or groups of actors pursue different interests, there is however a common ground on which everyone agrees. Strauss (1992) studied in particular the case of a psychiatric hospital. He claims that the members of the hospital share the same goal: patient’s well-being. All members can work together on this common basis: "*This objective is the concrete symbol by which, in metaphorical terms, the organization maintains the symbol to which staff can comfortably and frequently refer - with the assurance that on this point at least, everyone agrees* "(p. 95). The common basis for us is a process of social stability or capacity for understanding changes or failures.

This work has a double interest for us. Firstly it opens a door to the treatment of weak signals by placing at the heart of it the process of the social interaction between individuals and organizations. Secondly, it can solve, at least in part, the difficulties of processing weak signal which lie in their nature as uncertain and incomplete information and in the factors that block their

[16] According to Reynaud (2004), learning takes place through a process of negotiation between individuals, to establish a new order following a change imposed by the organizational requirements of competition, or of improving performance. This new order generates new forms of working and therefore the need to learn new skills, new methods and professional relationships. We see learning as a collective dimension of organizational change, so it is not the organization that learns of itself, but it is the individuals who invent new forms of relationship to establish or restore the social order of the organization of which they are the members.

interpretation - the rigidity of interpretation frameworks. Sense-making processes lead organizations to:

-Make sense of weak signals by attaching to them a criterion for selection and transmission, the degree of dissonance or surprise engendered, which therefore recognizing their specificity,

-Treat weak signals by making connections between them and other data thus acknowledging and nullifying their fragmentary nature. This transforms data into information and knowledge accessible to individuals,

-Promote vigilance for upstream events and recognize the power of anticipation.

In this perspective, we acknowledge that the interest in the phenomenon of weak signals lies as much in the insight they bring into the sequence that leads to the accident as in the learning they can provide at the individual and collective level.

2.4.4.4 Deutero learning*:* learning to responding to weak signals

But we still have one question. Organizational learning that would enable the appropriate treatment of weak signals appears largely based on a social process. Is it possible, in our attempt to formalize and "operationalize" weak signal treatment to integrate this dimension into a more formal applied model such as that proposed by Koornneef (2004)? How is it possible to build and to formalize learning on the basis of weak signals as we have developed them throughout this literature review? The case study chapters will give us some answers to this question that we consider essential in this research.

2.5 Summary and conclusions

We demonstrated initially that event analyzes provided an essential understanding of weak signals. Indeed, they reveal the need to analyze an accident or a critical event in all its complexity, that is to say, taking into account the technical, human and organizational aspects. Our strongest assumption is the belief that accidents always have a phase of preparation or incubation, which it is possible to throw light on accident analysis. Signs warning of a potential safety hazard emerge during the incubation phase which implies two important conclusions: firstly that such warning signs exist and second that there is a latency period upstream of the critical event which can allow the organization to implement actions in response to these signals to prevent the critical event. By combining these two approaches, we have proposed to identify weak signals as signs of failure (or deviation) in an organization's ability to master the risks inherent in its business. To detect these signals of incipient failures, but above all to understand the logic of their combination, would be the preferred course of action for accident prevention. Event analysis can potentially reveal the existence and relevance of weak signals.

Then we discussed Rex as a process of retrieval and analysis of events, put in place in high-risk organizations but shown so far often to be a relative failure for the following reasons:

-Rex is based too exclusively on the identification of technical factors,

-Rex is based solely on accidents and incidents not on minor events, weak signals and good practices,

-Finally, Rex would fail to meet the objective of the learning: few lessons are drawn from the events, given the "narrowness" of the analysis that the Rex usually seems to produce.

A formal and reactive Rex does not seem to represent an appropriate way to integrate and operationalize the weak signals in the system of safety management.

Faced with these difficulties, we proposed a method of risk control built on the work of Hale. The Delft model is a prescriptive approach to guide organizations in the identification of where, and what sort of signs can emerge of a loss of risk control. This model combines in a dynamic way:

-Identification of hazards to safety and checkpoints to control the occurrence and consequences of accidents,

-The provision of resources and controls at three levels of execution, management and safety policy, whose objective is to maintain control of risks in as reliable a state as possible,

-Organizational learning, involving the establishment of organized functions dedicated to learning, constantly evaluated and improved.

The Delft model clearly contributes to the definition of weak signals, guiding organizations towards the identification and treatment of signs of loss of control of risk, within a framework of constant reassessment of the control model.

Our goal is nevertheless to achieve a more substantial understanding of weak signals. We seek to understand both the nature of weak signals and the operational interest they have for risk management, and the process of their detection, transmission and processing. We have defined weak signals as possessing information of a specific nature, fragmentary, uncertain and "surprising", which has within it the power to anticipate a phenomenon - the occurrence of an accident in our case. The operational significance of weak signals, their informational power and power of anticipation, are the main reasons for trying to detect, capture and process them. What is therefore necessary is to make the effort to extract these signals from background noise, that is to say, to recognize the signals with potentially relevant information.

The system for encoding and decoding of information implemented in an organization, we have seen, is not always appropriate for consideration of weak signals. We have categorized the factors blocking the interpretation of weak signals as:

-Beliefs and convictions and a culture leading to the emergence of progressive blindness to risks,

-A complex organization of work leading to fragmentation of sources and flows of information,

-Production pressures treated as a priority, relegating the treatment of weak signals of safety to a secondary activity.

These three factors cause individuals and organizations to ignore or misinterpret the warning signs on safety. We recognize that the categories of interpretation of information in organizations currently may not be suited to dealing with weak signals.

We have subsequently proposed a way of handling weak signals. This consists of:

-A review of the analytical categories used to classify information for treatment:

It is first necessary to recognize the rigidity of the frameworks for interpreting information and, secondly, to deal with weak signals at several levels: individual, cognitive and collective. It is therefore necessary to select and transmit data according to the criterion of degree of surprise they bring, and to challenge the interpretive frames previously accepted as suitable for interpreting them and turning them into information, and by so doing to open them out and readjust them to treat this dissonant (hidden) information. Organizational reliability depends on the capacity of individuals to participate in and give meaning to this organization, including interpreting the potential information alerting of a danger to safety.

-Stabilization of frameworks for interpreting information:

We recognize that it is through stabilization (or even routinization) of the process for detection, transmission and interpretation of weak signals that they can be treated. This stabilization may be helped by the formalization of the process of sense making that we have described. In this context, we propose a method for handling weak signals which lies at the intersection of the humanities and social sciences (combining as they do a consideration of both the cognitive and individual dynamics of organizational learning), and the management sciences in recognizing the need to stabilize through a process of formalization, the social process of learning. We hope that this "integrated" method will respond in a less prescriptive way to the problem of organizational fragmentation affecting the quality of the transmission of information such as weak signals.

Chapter 3 will deal with methodology applied for this PhD research.

3. Methodology

This chapter aims to set out the methodological approach used for this work. We shall present first the global methodology, action-research, by returning to its origins and its relevance within the framework of this research. Then, we shall set out the content of the "research" part, more particularly the realization of case studies, choice of the sites, the tools for collection of data, as well as the modelling of the data. Finally, we will approach the "action" part of this methodology, including feedback of the results and proposed recommendations to both companies involved in this research, ACIO and EDIA.

3.1 Research question: relevance and feasibility

3.1.1 The relevance of weak signals

Literature review dealt with the theoretical interest and relevance of weak signals in the safety management field. We tried to show how this issue emerged (essentially from accident analysis), how it could be used (in improving learning processes such as Rex), why they might be weak or weakened (organizational blockers weaken the message transmitted by these signals). We concluded that a better treatment of weak signals, by opening up the framework of signal analysis, may contribute to improve learning processes.

My objective in this chapter is to pose questions about the existence of weak signals, in empirical and practical terms. Have weak signals already been studied through empirical surveys? What are they concretely? Do they exist both for the researcher and the practitioner? As long as weak signals are studied using a single theoretical perspective, the question of their practical relevance and existence will remain. We strongly (although modestly) wished to contribute to a clarification of this.

After trying to define weak signals from a theoretical angle (chapter 2), this PhD research will attempt to take up another challenge. We will put effort into testing the empirical relevance of weak signals. As stated earlier, we missed empirical surveys that could define weak signals from an empirical angle. Our objective, therefore, is to collect data that may define concretely the notion of weak signals. Then, we will study the potential operational contribution of understanding weak signals by conducting a collaborative study with the industrial partners, and trying to answer their concerns: how could they better detect and treat weak signals in order to improve their Rex processes?

Action-research appeared to be a relevant methodological approach to deal with this twofold objective. Action-research is composed of two steps. The first stage is a deep diagnosis conducted in a fieldwork. For this PhD research, we carried out two case studies (with a qualitative sociology methodology, which we will deal with in section 3.2) in two industrial sites: a refinery EDIA and a steel-making plant ACIO. These case studies enabled us to put weak signals to the test of "reality". The second stage is one of action. In collaboration with the industrial partners, we put weak signals to the test of "operationality"[17], meaning their usefulness in practice.

During this research, we paid attention to the various definitions of weak signals in literature (Vaughan, 1996, Caron-Fasan 2001, Dien & Pierlot, 2006, Julien & al. 2002, Macrae 2007, etc.) and those offered during the biannual FonCSI seminars (Brizon, 2007), and concluded the following. In the first place, the notion of weak signals covers a multitude of terminologies: "forerunners" or "precursors" and "warning signals", are some of the many synonyms used to describe weak signals. We also noted a difference in the way of understanding weak signals, according to the professional role (researcher, industrialist), the knowledge acquired about the notion and also the attention which is paid to it. Finally, and on the basis of these first two conclusions, weak signals often arouse controversy. They are perceived on the one hand as obvious, incontestable evidence permitting the application of elements from disciplines such intellectual trap", implying great difficulty in apprehending this notion -in as management sciences, sociology, or psychology to the study of risks. On the other hand, weak signals were entitled an " particular at an operational level – and of drawing lessons from them.

Given the recent nature and emergence of studies on this subject, weak signals seem more defined on the basis of common sense notions than on any established scientific definition. We underline the still fragile anchoring of this notion in any one (or several) scientific disciplines and the difficulty of understanding it in either a theoretical or practical sense. Thus, the objective of this study was to carry out a study allowing us to question the relevance of weak signals, as scientific and practical objects, without claiming to bring satisfactory and exhaustive answers.

[17] My intention to justify and show the relevance of weak signals is caused by my intention to test the issue of weak signals, in the sense of breaking with "prejudgments", as Durkheim says. This represents an indispensable approach to begin a scientific work. Bachelard, also quoted by Dantier (2004) writes in his turn that "*Science, in its need for achievement as in its very principles is opposed absolutely to opinion" (…). Nothing can be based on opinion: it is first necessary to destroy it*". He goes on: "*Above all, it is necessary to know how to raise questions. And whatever we say about it, in scientific life, questions do not arise of themselves. It is exactly this sense of questioning that marks the real scientific spirit*." (Dantier, 2004, p. 5).

3.1.2 Empirical and operational relevance: action-research

This section is dedicated to the presentation of the methodology and pursues a double objective:

-The definition of the notion of weak signals and their specificities, which guided the collection of data (see section 3.2.3) through interviews and observations,

-The development of operational recommendations for both of the case study sites at ACIO and EDIA.

To guide our project, we used a method applicable on both the practical and theoretical levels, action-research. Goyette & Lessard-Hébert (1987), in their work dedicated to action-research, describe a number of practices. We follow their proposition: "*Several authors recognize (thus) in action-research aims of research, of action and of training, and characterize it by the capacity or the will to envisage all of these aims at the same time. (…) It seems that the majority of authors pursue objectives which touch at the same time all of these three dimensions. We shall respect this complexity* "(p. 24).

The difficulty to solve this complexity may come from the conjunction between, at a first glance, two contradictory terms: research and action. Gaulejac (1992) raises the contradiction between a critical position – that of the researcher- and that of the action-oriented adviser, by evoking the relationship of power between the researcher and person commissioning the work. By revealing the underside of the functioning of an organization and the devices which govern the relationships between individuals, the action-researcher demonstrates the opaqueness of this power and temporarily deprives the principal of it. The intervention of the researcher goes beyond these questions. If he/she structures the intervention as a conflict of knowledge and thus of power with the organization, then we can doubt the value of his project. When a researcher ventures to share "his ammunition of power" which is his understanding of the organizational mechanisms, he also gives the possibility of opening up perspectives of mutual understanding. Action-research is not, for us, a relation of power but rather is one of collaboration and support/advice to the project. The results enrich not only the practices and knowledge of the researcher but also those of the commissioner of the work. We thus subscribe to Uhalde’s proposition (2001) which speaks about a “situated (or privileged and not contradictory) position” by the intervention in company.

3.1.2.1. Action-research; the involvement of the researcher

First of all, action-research is characterized by the involvement of the researcher (cf. Goyette & Lessard-Hébert, 1987). From the beginning of our research, we directed our work towards producing change. The limits (in the success) of this stance will be discussed at the end of this chapter and in chapter five and six. Let us return first of all to the three dimensions of action-research: the purpose of the research, the purpose of the action and the social purpose.

We adopt from a sociological intervention - which is one form of action-research[18]- the importance which it gives to the dimension "research" and which, for us, is central in this work. It is essential for the researcher to dive into the organization by taking time to understand the context, the organizational structure, and what is at stake in the subject being studied, in order to better assess these "problem situations". Hatchuel (1992) writes: *“Sociological investigation allows us to raise “open problems”* that is *“problems about which questions, controversies or conflicts exist in the company and to which the researcher can also associate more general problems.*” (p. 78).

The questions actually put by the commissioner of the study often conceal or translate such questions of a more general order; the challenge for the researcher, asserts Hatchuel (1992), is to seize the opportunity to progress towards these wider questions.

3.1.2.2 Action-research: a process of mutual learning

Réhaume (1982) reminds us that the researcher is involved both in the research and in the organization in which he intervenes. Part of his work is to define exactly, with those commissioning the work, what are the objectives of this research.

From the genesis of this project, we worked with the case study partners to find a common purpose between them and the research team. A launch meeting was organized in December 2005, gathering the representatives of the partner companies, ACIO and EDIA, our research team and FonCSI. The discussion resulting from this meeting centered around two different perceptions: a research project on weak signals presented by the research team, and the operational requirements of the companies aiming at a better treatment of weak signals. We are used to reading in descriptions of this type of research, that the companies are invited to stand back and question their practices - here the Rex system of learning from experience and the issue of weak signals - but the complementary adjustment is hardly ever evoked. Nevertheless, we think that researchers also need to revise their approach so that it is understandable, operational and applicable (what we tried to do).

Réhaume (1982) indeed specifies that the involvement of the participants in action-research creates new connections between knowledge and practice in terms of learning. Action-research becomes educational because it modifies the modes of interaction; it is re-educative in so far as it introduces new standards of functioning and favors a context of symmetrical exchange between researchers and those commissioning the work. Learning is thus mutual, built upon an initiative of

[18] We did not describe here all the existing forms of action-research, because it would lead us into a major additional area not relevant for this thesis. We indicate simply that action-research includes among others (and this list is not exhaustive): sociological intervention (Uhalde, 1999, 2001 and 2002), the psycho-social intervention in organizations (Gaulejac, 1992, Enriquez, 1992), and interventions in the fields of the education and training (Lewin, 2008 and Réhaume, 1982).

mutual adjustments not only to the content but also to the modalities of the intervention, for the researcher and the sites.

Mutual learning summarizes the type of research we wanted to carry out. However, our experience with the field caused us to revise our objectives and to accept that this sort of ‘democratic’ project is sometimes difficult to realize in full. We shall return to this point in chapter five and six.

3.1.2.3 Action-research: a social purpose

In addition to the modalities of research and of action, we realized during the project just how much there was also, at least implicitly, a social purpose. Uhalde (2002) teaches us that the practices of action-research should incite researchers to answer problems specific to the organizations, while taking into account the relations between the working groups and the whole organization. He notes that such an intervention conveys also an aim of democratization. The researcher advocates not something "better" - that stance would be prescriptive - but a "good" in a collective move where all the actors in the organization participate in a reassessment of their position and its history. Restoring to actors their voice, and their access to information and to participation, as well as confronting different social logics (those of operators and managers) and favouring resolution of issues and not conflicts, implies a project of learning "to live together" or a process of cooperation between intelligent beings (Dejours and al, 1994).

However, we are forced to question the real democratic impact of the action-research which we tried to implement. In spite of our desire to give “the word” to staff (operators, technicians, team leaders, members of committees for health and safety at work) and managers – the final results and recommendations stemming from this work were only delivered to and debated by the headquarters/management teams of both sites. I spent most of the time with people lower in the organization, so that they were involved in my project. This raises the following question: are the modality of hearing about, and use of the results and actions ensuing from our research, symptomatic of the power relations in the organizations? To what extent can action-research, aside from its link with the managers, facilitate cooperation between leaders and staff? The "social" effects of this research will exceed certainly the scope of this study. But by underlining this limit we can also indicate that, despite what the researcher may wish or aim to achieve, action-research can result in the maintenance of social (and asymmetric) mechanisms in any organization.

To summarize, action research represents an ambitious project in so far as it implies carrying out a high quality diagnosis, making proposals for understandable and operational recommendations and, in the end, achieving a change in the practices, and even in the values, of the industrial partners. We have suggested that these three requirements might be difficult to satisfy within the framework of a single thesis. This question will be raised specifically in all of the subsequent chapters of the thesis.

Figure 8 illustrates the phases of action-research which we are going to develop in the following sections:

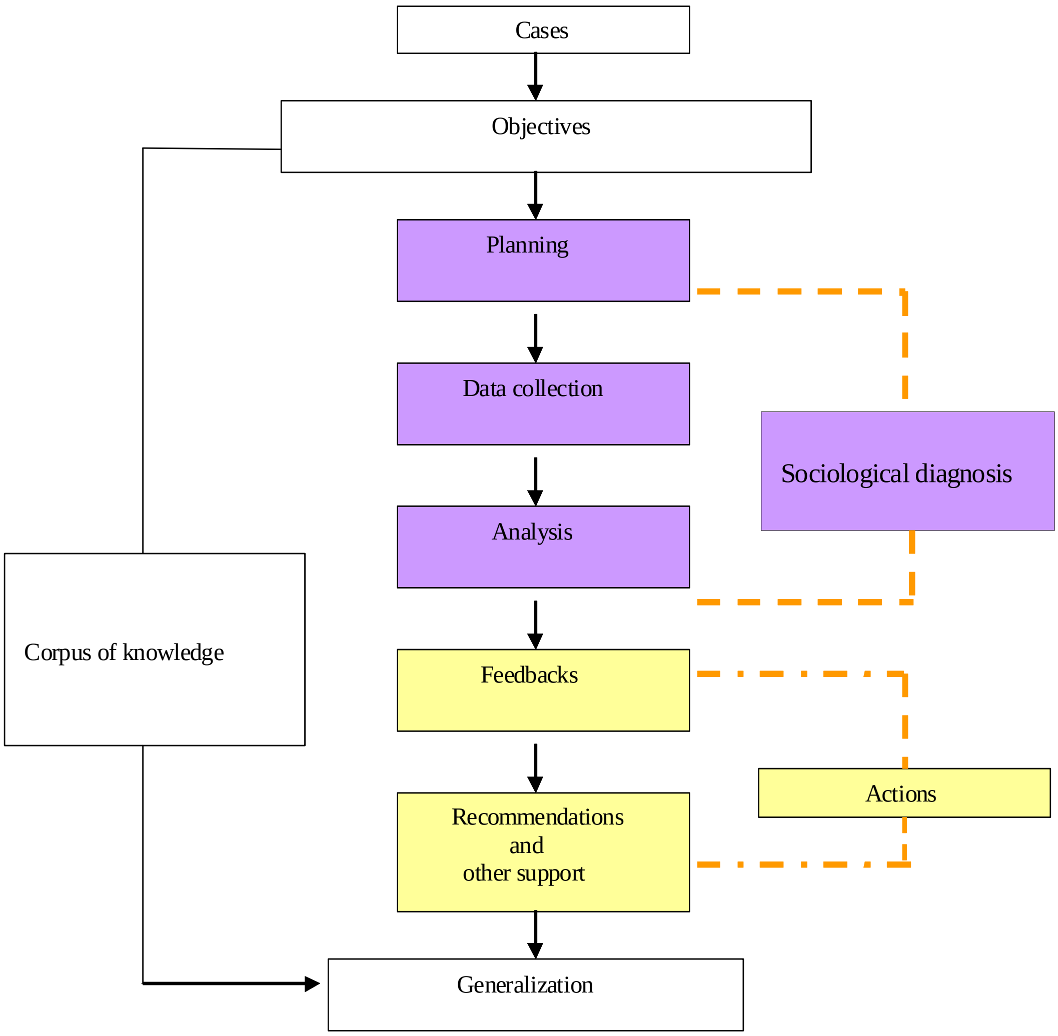

Figure 8: Action-research based on case studies, inspired by Leplat (2002).

Legend: violet steps stand for diagnosis or research, and yellow steps stand for « action ».

The following sections describe and explain the stages of action-research as we conducted it during this thesis. We shall return in the first instance to the sociological diagnosis - choice of sites, data collection, the process of analysis and the feedback- and recommendations proposed to both industrial sites.

3.2 Sociological diagnosis: choice of cases and data collection

Building a research question and providing some answers, is a funneling process, starting from a broad set of questions and, finally determining the one which will guide the work. The chosen methodology allows us to bring a set of elements to bear on the issue of weak signals. In order to collect a range of empirical facts to understand the phenomenon of weak signals, our choice was for the realization of case studies, placing the emphasis on direct observations and interviews. Yin (2003) teaches us that "*The case study, like other strategies, is a way of investigating an empirical topic by following a set of pre-specified procedures* ".

The choice of sites, the definition of the themes to be studied and the tools to be mobilized constituted the key stages of our case studies, which we will describe in the following sections.

3.2.1 Defining the sites for the investigation and collecting data

Case studies were carried out on two sites: a steel-making plant, ACIO, and a refinery, EDIA. The two representatives of these sites, who were involved through their links to FonCSI in the research program on Learning from Experiences (Rex), showed their interest in the topic of our research when it was proposed. They saw the opportunity to deepen their knowledge of weak signals and the possibility of improving their companies' treatment of them. They decided to participate and get involved in this project, in particular by proposing the access necessary for the carrying out of case studies in their sites in Belgium, which had shown a particular interest in the topic. In the first instance this choice of sites seemed appropriate given the involvement of the Delft University of Technology, based in the adjacent country of the Netherlands, in the project.

3.2.1.1 Case studies: requirements revised

In the original plans of 2005 for this research project, case studies in the two companies showing interest were to be conducted in two sites situated in Belgian Flanders, and first contacts were made with them. However, this would have required the learning of the Dutch language. In practice, in spite of an extensive course in the language, the level acquired was not sufficient to realize case studies in Dutch. Once the literature review stage of the project had been finished and it was clear what the research methodology would be, this problem had to be resolved. In a sociological approach, in which interviews and observations are the main tools, an understanding of the delicacies of the language is vital to seize the full meaning of interactions. Hence, it was decided that the use of my mother tongue was imperative.

To be able to continue, we negotiated an access on two French industrial sites of the same two companies, ACIO and EDIA. This decision and request was supported by FonCSI, the representatives of both companies involved in the Rex research program (presented in Chapter 1) and our team of research. However, the process of discussing and 'selling' the project had to begin again, because both French sites which finally welcomed me had no direct knowledge of either the Rex program launched by FonCSI, or of the issues surrounding weak signals. Presentations were made on each of the two sites in April 2007. The objective was to describe my research project, its research questions, methodology, modalities of access, but especially to convince them to get involved and to allow us to use their sites. After this, it was agreed that both sites would welcome me to carry out case studies.

Both sites were classified as high level SEVESO sites, having storage and use of more than the threshold level of dangerous chemicals. Both were therefore required to, and had set up, within the framework of the decree of May 10th, 2000, a Safety Management System (SMS), including a Rex feedback and learning system. They both found the issue of weak signals interesting, because more attention to them could potentially supply improvements in their practices of Rex. The reason for explaining this step in detail is to raise the question as to the degree and real depth of involvement and commitment of these two French sites. We defined action-research earlier as a collaboration favouring mutual learning which implies a committed involvement of both parties (the researcher and the sites). Because they were appointed by their head quarters companies, rather than being enthusiastic volunteers (as their Belgian counterparts had been), it is relevant to ask to what extent these two French industrial sites were volunteers to participate in this research? Was the issue of weak signals a question on which these sites were really ready to work? Were they prepared, in making their decision to confirm their participation, in particular for the phase of 'action' (feedback and recommendations), in which they needed to have a very committed involvement in order to do something active with the feedback? In chapter four, the EDIA case study, and chapter six, the final Synthesis, we shall return to this question, particularly as it concerns the role of the sites' involvement in the feedback, the follow-up and the consideration and eventual acceptance of the diagnosis.

3.2.1.2 Case study planning: between initial plan and negotiation with industrial partners

To intervene on two industrial sites, whose activities and technology are complex, required careful preparation. We describe briefly the stages of this preparation because they turned out to be beneficial for the realization of the case studies.

3.2.1.2.1 Case study preparation

For each of the companies, before carrying out the case studies proper, we proposed a preliminary period of "immersion" in order to acquire elementary knowledge on their technology, management and safety.

The EDIA safety department welcomed me for five days. The company ‘preventionists’ (safety professionals) took care of my introduction and integration and allowed me to visit the refinery and to acquaint myself with the safety, quality and environment department (QHSE). I[19] also had the opportunity to participate in the daily operational meetings and observe preventionists during their safety audits in the field. ACIO welcomed me for ten days. The safety department organized for me a visit to each of the five operational departments of the steel making plant (see appendix 9), and gave me a presentation of the Safety Management System – the procedures, the tools such as Rex and safety audits.

Preparation had two objectives: to acquaint me with the technical aspects (refinery process and steel making process) and the safety management, but also to introduce me to the persons on site, particularly the preventionists or safety coordinators, who were to become important informants for the case studies. The ACIO and EDIA heads of the safety departments took the role of industrial mentors - they were concerned with the quality of my integration in safety department and the rest of the organization - and the preventionists helped me to meet relevant people and to get access to data.

3.2.1.2.2 Case studies, first step: a too limited planning

The phase dedicated to the collection of data on accidents and normal functioning for the case studies was conceived, in agreement with both industrial partners during the conception of the project, as a block with duration of four months: two months for each site. At that time, it was necessary to limit the time asked for, in order to reassure both partners of the limited demands on their time and resources, so as to obtain an agreement for access to the sites. However, in the inductive approach proposed by Grounded Theory, which we followed, case studies cannot be guaranteed to fit into a limited time. In the first instance, the researcher needs time to immerse herself in the site and observe the functioning of the organization (acclimatization period) and, in the second instance, to find where and when to conduct observations and interviews (period of diagnosis). These two periods cannot be squeezed in advance into a given, limited time because of factors which can make them vary, such as availability of people, periods of inactivity of the site (in July and August), which can block access to the data and extend case studies periods.

We stuck initially to this planning but the two months granted were not sufficient to collect all the necessary data. In that time, on the ACIO site, we studied six accidents; on the EDIA site, only

[19]“I” is specifically used to emphasize the activities I personally, as a researcher, carried on.

the normal functioning. Both blocks of two months appeared very short. A negotiation with both industrial mentors was necessary to obtain an extension to collect complementary data and our request had to be explained and justified. Researcher time is an indispensable resource to be used to understand, observe and conduct research. The requirements are envisaged long-term. On the other hand, time in an industrial site, at least for both mentors, is seen as something of the short and medium-term. To their point of view, asking for additional time was perceived as a set-back, a difficulty in organizing my case studies or in optimizing the resources provided. From a strategic point of view, this access to the site was important and we therefore used the argument to convince them, that additional access would allow us to deliver an in-depth analysis of the relevant organizational complexity and to realize a good diagnosis and propose operational recommendations. This was found to be convincing and a second access period was accepted, within which we were able to complete the case studies.

3.2.1.2.3 Case studies, second step: collecting complementary data

Once both sites had agreed to the second phase of field data collection, we collected the missing data: analysis of a complex accident on the EDIA site and the normal functioning at ACIO. Altogether, we stayed five months on each of the two sites.

It is always difficult to judge in action-research whether sufficient data have been collected or not. We determined three criteria to “stop” the collection of data. The first one was relatively objective; we concluded that the data on the normal functioning and the accidents was sufficient in so far as they gave a satisfactory understanding of the SMS and organizational learning system and that they allowed us to grasp the issue of weak signals. The second one was more subjective. This was when we “felt" that collecting more data would not enrich any more the guiding principle of the thesis. Collecting or accumulating too much data might then have driven us to confuse the issue, clouding our understanding of the issue of the weak signals. Thirdly, as we had already asked the companies for an extension period for each of the case studies, which meant that they had to provide extra resources in terms of time and availability of their people, we considered that we could not negotiate a third period for the case studies. In the end data collection has to stop. Although comfortable and exciting, data collection is just the first step of the thesis and time has to be left for the ordering and analysis of the data.

Nothing guarantees the relevance and the sufficiency of the data collected. I tried to find a balance between the constraints of the site - access, availability of the persons- the constraints of time in which the thesis has to be conducted and personal and university constraints. PhD research is in sum a complex process of managing a whole project and satisfy different, often conflicting, requirements.

In summary, we would like to emphasize two important elements of this research. In the first place, the case study protocol as initially designed was changed profoundly. The constraints we described above delayed and extended the period of data collection. Then research requires time, and a second access to the fields had to be obtained in order to fulfill my objectives, which revealed profound differences in the perceptions of the time imagined necessary and the actual time which had to be used.

After having explained the way the case studies were negotiated, we turn now to the contents of the case studies: what and how to observe? These are the questions which we raise in the following sections.

3.2.2 What data to collect?

To study the "organizational material" (Bourrier, 2001), we opted for a qualitative approach close to that proposed by Corbin & Strauss (1998) within the framework of Grounded Theory. These authors underline the importance of the flexibility of the researcher in the choice of the interviewees and the places and moments of observation. We are in agreement with this need. However, we have shown that carrying out case studies is a time-limited activity, which required of us the ability to define, relatively early, the scope required of the interviews and observations. Malinowski (1944) quoted in Vigour (2005) writes: *"To observe is to choose, it is to classify*" (p. 16). We would add that grounded theory does not mean ad-libbing; it requires rigor and determination, as efficient “armour” against the vagueness in which the researcher can get lost.

As mentioned in chapter one (Introduction), this research is focused on operational weak signals and the tools and operational processes that may process and give sense to them (Rex is part of these processes). We made a choice, for data collection, to focus the observations on the ground, where operational activity may be comprehended.

3.2.2.1 Accident analyses and success stories

As both the ACIO and EDIA sites are vast, we needed to limit the scope of the observations and interviews. These choices of what and how to limit have to have a "social relevance" (Arborio & Fournier, 1999): "*What matters is the fact that they (the social situations to be observed) can be completely covered by the investigation, in the sense that do not contain too many ramifications, and that they do not require the researcher to be everywhere*" (p. 25).

It was thus necessary to define the relevant social situations for the data collection. "*Social relevance means that the social situations chosen are embodied in a separable entity, analyzable for itself, in connection with the question being handled. It is necessary to understand them as a set* *of social relationships contributing to a common meaning (a production situation … for instance)*" (Arborio & Fournier, 1999, p. 26).

Three focuses were defined for the collection of data: the study of success scenarios, of accident scenarios, and of the normal functioning of the SMS.

We show, in the following sections, to what extent these three approaches answer or not the criterion of social relevance.

3.2.2.1.1 Success stories

Study of success scenarios was the first approach considered for conducting case studies. Success scenarios were, to us in the first instance, events which had enabled a site to learn lessons without an accident having occurred and to generate an improvement in the working practices because the site had picked up the sort of signals which otherwise might have been seen as weak and had made a change which plausibly had averted an accident.

We supposed, a priori, that these scenarios would exist on both sites and that changes and improvements would have been made because of them, but we had difficulties in finding a method to observe and analyze them. What we found was that, in contrast to the accident scenarios, successes are not analyzed in any formal way (within the Rex process, for example). When I asked the question “How could I study success scenarios?" the actors on the sites were amazed. According to them, successes are not events; they are not included in the Rex process because they are seen as part of normal functioning. So, we raised the following question: “is it possible to analyze success stories with the same methodology of accident analysis, that is to say by describing the event sequences and identify causes of success?” A priori, and according to the answers provided by the actors on site, successes are not observable in terms of scenarios, since they are not handled in a systematic and formalized way (there are no reports, databases or analyses for success stories, in contrast to accidents and near misses). Since we did not have other ways to look for success practices, the idea to analyze success stories thus ended in a defeat. They did not answer the social relevance requirement (evoked by Arborio & Fournier, 1999) because no actor defined them as observable by the researcher.

For the case studies, we were forced to change the definition and treat as successes the changes which were made after accident and incident scenarios had been investigated, contrasting those with the issues which could have been learnt from those accident scenarios but were not. In other words, we focused on successes and failures in learning from accidents.

3.2.2.1.2 Accident analyses

**** Definition and relevance***

Dien & Llory (2006) among others indicate that accident analysis provides enlightening insights. First of all, it allows us "*to identify the major organizational pathologies*" (p. 10) by shining a light on those dysfunctions which "*interact and develop into a serious pre-accidental situation"* (p. 10). Accidents act then as a "revelation" because they contribute to make *" clear and evident the phenomena which were still ambiguous the day before the disaster* " (p. 10)[20]. Event analysis shines the light on pathogenic factors, and, on the basis of this analysis, enables us to develop measures ensuring that the event does not repeat itself. Hence, accident analysis reveals a "*temporal reality"* (p. 10). While an accident takes place in a relatively fast dynamic, the slow reconstitution of the events during analysis reveals dysfunctions which are sometimes old, anchored in organizational practices. In contrast to success stories, an accident is a much more tangible phenomenon, fixed in time and, most often, documented (by internal accident analysis for example). Accident analysis, digging for these underlying factors in the organization was a very rich way, within this research, to collect data on the weak signals which had, up to that point, gone unheeded, which in turn threw light on the previous normal functioning (we are dealing with normal functioning in section 3.2.2.2). It was also possible to study what lessons the Rex system learned from those accidents (which we could treat as learning successes) and any potential lessons from our own analysis which the company Rex did not appear to learn even this time (signals which remained weak even after the strong signal of an accident).

**** Data collection strategy***

Accident analysis provided relevant insights into weaknesses in organizational factors (at least those involved with the accidents we investigated) and hence on the issue of weak signals. So we chose to study accidents scenarios on both sites. Before my arrival on the sites, a proposal covering the research and its methodology had been submitted to the industrial mentors of both sites so that they could facilitate the access to data. I defined the criteria for interesting scenarios to be analyzed as following:

-A recent event so that we could interview the people involved in the accident

-A process accident (and not occupational injuries sustained around the site)

-A well-documented accident so that we could have complementary data and see how the company had investigated it.

ACIO site preventionists selected a set of accident scenarios, before our arrival on the ground, according to the criteria we had proposed: they selected recent events (occurring between 2005 and 2007), process accidents (fires and explosions), which were well documented (Rex and technical

[20] See also section 2.2.2.2 in literature review.

documentation, safety committee documents, pictures etc). The preventionists facilitated my access to data which they could help to explain because they were experts on safety who, at the same time, had a strong technical knowledge. They also acted as linking pins, through belonging to the central safety function and being detached to an operational unit. Thanks to them it was possible to analyze six accident scenarios. One question must be posed but remains unresolved, relative to the choice of the scenarios. Since, on the ACIO site, the choice of the accident scenarios was made by preventionists, we have to ask whether this choice could have been biased: what motives might the site have had to propose these events for study? What other events were not chosen? Since there was no time to study other accidents in any detail, we cannot answer these questions. However, if there was bias we might assume that it would have been one towards showing the company in a good light, and underplaying the weaknesses in identifying weak signals.

At the EDIA site, we had to take the initiative in the choice of accident scenarios. In contrast to ACIO, and although it was a request in the research proposal we submitted, the preventionists did not propose any accident scenarios. Because of difficulties to access earlier data, we finally studied one single accident which occurred when we were conducting the study on the site. This was classified by the company as an occupational accident, but we chose to analyze it for the following reasons. First, the event was recent which implied that we could interview people involved in the accident as well as the witnesses. Then, although classified as occupational accident, this accident was one to a contractor doing maintenance work on the process equipment, and revealed deeper technical and organizational dysfunctions of safety. Finally, this accident was labeled “severity A” (A is a severe accident, B a moderate and C minor) according to the company severity scale. This meant that the SMS of the EDIA site applied a special procedure to analyze such a severe accident, namely an in-depth accident analysis (according to EDIA standards). The Rex noticeon such an accident has to be shared with all EDIA refineries, based on the company accident report involving both the site and company headquarters and on an accident reconstruction (judicial requirement). Because it was so well documented, this accident appeared to be an interesting entry point in order to study the Rex system and the results put in place after an event. The choice of this event having been validated by the industrial mentor, we proceeded to the interviews and the observations.

On the EDIA site and more so at ACIO, where six accidents were studied, data on the accident scenarios was collected in the following way:

-Interviews were held with the people involved in the accidents: operators, technical staff and safety experts, team and department managers. The interview guide is given in appendix 1,

-Internal documentation was studied: accident reports, Rex forms, reports of the Committee for Health and Safety at Work, pictures and technical documentations.

In the end, three of the six ACIO accidents proved particularly interesting and were investigated in more depth than the other three (we will say more on this in chapter 5).

To summarize, we benefited from two opposing strategies of accident selection and investigation at the two sites, which both have advantages and disadvantages. On one hand, the prior choice of the scenarios (ACIO) considerably facilitated access to data. However, we had to avoid a trap; namely just to conduct the same investigation already carried out by the site, which could have led us to draw the same conclusions. We therefore opened up the inquiry by taking an independent stance and by following our own method of digging into the scenario. This included conducting interviews with key people who had not been proposed by the preventionists as relevant, but who seemed to be so according to our ongoing investigation. It also included studying documentation which was not included in the official accident report – e.g. procedures of equipment lock off and work permits. My objective was to reveal dimensions of the accidents not yet formally and explicitly revealed. Being the one to make the choice of an accident scenario (EDIA), on the other hand, was instructive because it required me to argue the choice of this scenario whilst the company investigation was ongoing. The EDIA site, by accepting my choice, took the risk of me discovering a different set of underlying factors from the one they carried out. We shall see at the end of chapter 4 that there was indeed some reluctance from EDIA to accept the diagnosis we made.

"*The royal road of accidents*" (Dien & Llory, 2006) was certainly a source of valuable data which did, indeed, revealed organizational problems at the root of the phenomenon of weak signals (see section 2.2.2.2). However, the more we progressed in these investigations, the more we realized that, to get behind the problem of weak signals, we needed to assess the role and influence of the organization and the way it was set up. This brought us almost 'naturally' to approach the second aspect of the case studies, an understanding of normal functioning.

3.2.2.2 Normal functioning

Studying normal functioning required a different strategy of research to the one developed for accident scenarios. Whilst accident analyses certainly revealed the role of the "*banality of organizational life*", according to Vaughan's words, in respect of weak signals it was necessary to take direct measurements of them. Therefore it was necessary to define how to observe normal functioning, to analyze it and use it in a relevant way.

3.2.2.2.1 What do we mean by normal functioning?

We consider, in the same way as Bourrier (2001), that high risk organizations - at least those we studied - should not be studied using a different approach from that relevant for other organizations, because their characteristics resemble those studied by the theorists of organizations. She indicates a strong link between the maintenance of organizational reliability and organizational structure. By organizational reliability Bourrier (2001) means the study of the organizational conditions allowing a complex system to maintain levels of reliability compatible with safety and economic requirements. If we accept this link, it is necessary to describe this organizational structure in order to understand and observe reliability. If we also accept the hypothesis that attention to weak signals is a way to maintain and improve organizational reliability, that means that, in this PhD research, it is necessary to study the organizational structure and functioning at EDIA and ACIO, in order to identify the factors blocking the treatment of the weak signals and hence weakening organizational reliability.

3.2.2.2.2 Relevance and strategy for collecting data

By digging deeply into the historical and organizational dimensions of four accidents (three in ACIO and one in EDIA), we had uncovered the strong anchoring of weak signals in the normal functioning of the companies. Two aspects of the organization became clear in particular:

-The influence of the risk control system: tools, methods and underlying models applied in both sites,

-The influence of the organizational structure itself.

These were the aspects of normal functioning which we concentrated on, in order to provide relevant data for our research.

The study of the normal functioning was in my case doubly demanding. On the one hand we opted for an "exploratory" approach (Grounded theory) without preconceived ideas as to what was relevant, leading us to test out and try different ways based on observations and interviews which would allow us to assess the relevance of normal functioning in relation to weak signals. This strategy of investigation worried the industrial mentors somewhat, because it appeared too vague and intuitive (in contrast with the techniques and methods used within the sites, which were much more based on a ‘rationality’ manifest in procedures, facts and written documents). This posture was all the more difficult for me because it confronted me with difficulties in determining the relevant times and places for carrying out observations and deciding who were the relevant people to interview. On the other hand, a point which exacerbated the first, the fact that the time available at the sites was limited represented a very real constraint which forced us to determine as quickly as possible our research choices and to limit the search process.

We therefore chose to analyze normal functioning according to two points of entries: the Safety Management System (SMS) and the operational safety on the ground.

-SMS: this covered the tools, procedures and methods guiding both sites in their risk control (workplace injuries and major accidents),

-Operational safety: in this we focused on the way subcontractors and those company employees overseeing the contract work apply and, eventually, redefine these guides in the daily realization of their professional tasks.

These two points of entry offered complementary and relevant vantage points to tackle the issue of the weak signals.

3.2.2.2.3 Bias?

Arborio & Fournier (1999) remind us that direct observations can be subject to research bias because no explicit instrument mediates between the researcher and what is observed. The researcher selects, sorts, classifies, and inevitably interprets the data, but is this done dispassionately and without bias? We have already indicated in section 3.1.2.3 that action-research implies a social project and engages the social (even political) values of the researcher. The choice of a method using detailed case studies and particularly the fact that we were immersed in working at the two sites over a period of a year and a half, facilitated strong and frequent interactions with the people on site. How could we insure, in these investigation situations, the famous researcher neutrality? What value to attribute to data stemming from direct observations?

A first way to keep the necessary distance was inspired by Yin's work (2003). He writes: "T*he case-study, like other methodologies such as surveys, is a strategy in itself. It requires specific skills. A researcher has to be able to ask good questions, to be a good listener, to be adaptive and flexible, and unbiased by preconceived notions".*

I do not claim that I met all of these qualities perfectly. However, trying to adopt such a posture implies that the researcher aims at observing in the most neutral way which would guarantee a distance between the researcher and the research object, and limit the projection of personal values, opinions and theoretical frames or models guiding data collection and analysis. I also tried hard, throughout the case studies, to adopt a naïve posture, one of open surprise and interest in what was being told (as suggest Beaud & Weber, 2003), without expressing any judgment on it. Another technique to achieve this distance was to keep a "logbook" of all of these interactions, on which I could reflect, and which was presented and discussed at the monthly meetings with my research supervisors. This allowed me to create a distance, through the paper and feedback, to my feelings and to any misunderstandings which could have disturbed my investigations.

The following sections indicate in detail the data that we collected during both case studies.

3.2.3 Summary of data collected

We have described above three approaches to conducting the case studies: the study of accident scenarios, success stories and normal functioning. Once these three themes were fixed, what concrete data had to be collected?

We used the following tools:

-Directive and semi-directive interviews

-Systematic observation,

-Reading and analysis of the internal documentation.

Below we give a summary of the data which were collected on each site.

3.2.3.1 EDIA:

1. Participation in training courses: safety training (both short and long training)

2. Meetings : presentation of the research project to the Committee for Health and Safety at Work, participation in the site managers meetings, Health and Safety department meetings, quality meetings, safety information meetings, safety briefings with subcontractors, incident assessment committee

3. Interviews in relation to normal functioning with:

  -Chief maintenance manager, Maintenance methods manager, Manager of prevention planning, Contracts manager,

  -Manager of the inspection department

  -Safety, Health and Environment department: Department manager, Safety manager, Quality manager and her assistant, Health manager, Risk analysis manager, Nurse, Safety coordinators,

  -Technical departments: managers of technical departments 1 and 2,

  -Operational departments: managers of operational units 1 and 3

3. Internal documentation:

  -General: organization chart, detailed technical descriptions of site activity (refinery process),

  -Guides and procedures : Safety management system manual, Major accident prevention procedures, Inspection & Reliability manuals, Certification procedures, ISRS (International Safety Rating System) manual and requirements, Procedures for dealing with accidents, incidents, anomalies and major events, Risk analysis methodology, Permit to work system,

4. Observations of meetings and drills:

  - Operational anomalies meetings « Operational anomalies meetings »,

- Daily maintenance works meetings,
- Project meeting: Project for boiler maintenance,
- Emergency drills (major accidents, fires)

5. Observations in the field:

-Workforce audits, Equipment inspections, Quality audits, Observation of works maintenance with a technical controller: cleaning of a pipe after a large product leakage and observation of lock off and tag out of equipment,

-Interviews carried out for the accident analysis with: Maintenance manager, QHSE manager, Quality manager, Operational department manager, Technical operator involved in the accident, Operator and Manager of subcontractor company involved in the accident but not the hospitalized victim and the witness) and two EDIA preventionists.

3.2.3.2 ACIO

1. Training courses: safety training (both short and long training) compulsory for all people from outside coming to work within the site,
2. Meetings: presentation of research project to the Central Committee for health and safety at work (CHSCT - uniting the five committees of the ACIO site),
3. Interviews, documentation & observations concerning normal functioning:
    - Safety department: interviews:
        - Department manager, Safety staff, documentation: safety audit manuals and results
        - Environment and Major accident department: Department manager
        - Health department: Ergonomist
    - Operational departments
        - Steel works department: interviews with Department manager, Maintenance manager, and Prevention planning and contracts manager; observation of behavioural audits,
        - Coking plant: interviews: Department manager, Safety staff (2), Manager electrical isolation, Works maintenance manager: observation of safety audits,
        - Power department observations of two maintenance projects: a gasometer cleaning and maintenance of a convertor lining

4. Interviews, documentation & observations relating to accident scenarios. For each scenario, as a preliminary step, I presented my research project and methodology to the operational department manager, department staff meeting and technical staff meeting of each department I

would be visiting, so that they knew who I was and why I needed to carry out interviews and observations.

-Accident 1 (steel works plant): visit to the accident site. Participation in fault tree construction process, accident meeting, and process of writing the Rex notice, interviews,

-Accident 2 (energy department): interviews with expert on fluids, shift supervisor, operator. Visit to the accident site, documentation; pictures, and HSC report,

-Accident 3 (steel works plant): interviews with manager & shift supervisor for mechanical maintenance, maintenance fitter, operator, new projects manager, chemicals expert, departmental major accidents expert. Visit to the accident site, pictures and technical documentation.

3.3 Data analysis: from diagnosis to action

Data analysis using Grounded Theory is an extremely interesting and rewarding process but one which remains difficult to clarify and explain.

3.3.1 Analysis and comparison of data collected

3.3.1.1 The dynamic of interpretation

Grounded theory means, as its title says quite explicitly, that theory emerges from the ground or the field: "*A researcher does not begin a project with a preconceived theory in mind* (…). *The researcher allows the theory to emerge from the data*" (Corbin & Strauss, 1998, p. 12).

This assertion has strong theoretical and methodological implications. The researcher does indeed have to "allow" the theory to emerge from empirical data collection and interpretation, meaning a certain distance from established theory. However, we think that, at a certain stage, the empirical data analysis needs also to be referred to explanatory theoretical models which will guide the formalization of the results.

The process of data interpretation is difficult to explain succinctly because, in the same way as for the direct observations, I did not use an instrument or a tool of interpretation such as sociological analysis software. I am nevertheless going to try to present this crucial stage in the research work. Are these comments still of a methodological order? We believe they are, because they describe explicitly the path I took to build the results I found during this PhD research.

Corbin & Strauss (1998) indicate that data analysis is a process of interpretation, carried out for the purpose of "*discovering the relationships among concepts*" (p. 57) and organizing them into a theoretical explanatory scheme" The objective is not to describe reality in the raw, but to establish links, making sense of the relations within the data. In a qualitative and inductive approach, the interpretation is guided by an implicit mental process and by a mobilization of explicit theories (such as those we presented in chapter two). We undertook the interpretation of our data in the following way:

-Confronting the data collected on the normal functioning with that on the accident analyses

-Confronting these data with the literature and more exactly with the literature domains which constitute our research question - accident analyses, organizational learning, risk management, the theory of communication and the theory of organizations.

Using these two steps, we were able to interpret the data and propose the results which will be described and summarized in the chapters four, five and six.

3.3.1.2 Comparison

The final work done in this thesis consisted of the comparison of the two case studies (chapter six, Final Synthesis). Durkheim (1997) writes: "*Comparative sociology is not a particular branch of sociology; it is the essence of sociology, because it stops being purely descriptive and aspires to explain facts*" (p. 137).

The stakes are clear; comparison intends to reveal social facts more evidently. But comparison requires a meticulous methodological and theoretical elaboration which, for us, enriched and clarified our work. While comparison seems to be an evident part of social sciences, works dedicated to this subject are cruelly missing. We shall lean on the clear and practical work of Vigour, *Comparison in social sciences* (2005), and raise the three following questions: why to compare, what to compare and how to compare, in order to describe the contributions and the limitations of comparison in our work on the weak signals.

3.3.1.2.1 How to compare?

We opted for a case- oriented approach to compare the two cases from the ACIO and EDIA sites. According to Vigour (2005), this strategy allows a detailed empirical study of the cases and to put the emphasis on their similarities and differences. Table 1 synthesizes the strategy of analysis by case that we followed:

Strategy	Characteristics
Method	Historical, contextual, complexity of factors and causal relations
Materials	Interviews, observations, documents
Number of cases	Few
Level of abstraction	Limited
Level of generality	Specific cases
Limits	Case studies limit generalization (comparison of two cases here)
Objective	Formulating hypotheses and testing the relevance of theories for the results found.

Table 1: Strategy of comparison based on case studies (Dogan & Pelassy (1982) and C. Ragin (1987).

To ensure the comparability of the cases, Vigour (2005) says that it is first of all necessary to use the same method of investigation in the various phases of the investigation. For example, she recommends the use of the same interview guides for both studied cases. We followed this recommendation and elaborated a common strategy for collecting data on accident scenarios in ACIO and EDIA, and a common strategy to collect data on normal functioning. Secondly, it is important to define exactly the object of the comparison. Sartori, quoted in Vigour (2005), asserts that comparison is "*to assimilate and to differentiate according to a criterion*" (p. 3). Comparison is not self-evident; it is a process of building the objects to be compared. It leads to a systematic confrontation of the two cases through the spectacles defined by the researcher. From its beginning, the issue to be compared in this research was already defined, the integration of weak signals into Rex (experience feedback).

3.3.1.2.2 The possible limitations of comparison

Chapter six will deal with the results emerging from the comparison of the case studies but we think it is useful to give some elements of the answer here, in order to discuss the limitations of the method of comparisons. The work of Vigour warns of the dangers of comparing phenomena which are rooted in specific cultural, historical or social contexts (see table 1). Despite our efforts to define clearly the notion of weak signals, and to adopt a common strategy of investigation of the accident and the normal functioning in the two companies, which should make comparison more valid, we need to raise the following question: is it really possible to compare the issue of weak signals in Rex from the study of only two unique cases, at two industrial sites with very different activities? There is a danger that the findings will refer to practices and representations characteristic of, and limited to the specific contexts in which they have been observed. Vigour (2005) uses the example of socio-professional categories in different European countries to show that certain categories can be the result of a process of social construction and that their meaning refers only to the context in which they were developed. Therefore any comparison must take note of this phenomenon of social construction.

Bourrier (1999) compared four nuclear power plants: two French sites and two American plants. To her, it was necessary to avoid explaining the variation between her cases by cultural factors and context. She overcame this pitfall by revealing the "endogenous" organizational dimensions of the four sites she investigated, to compare the differences and similarities between the four power plants. This puts the emphasis on internal consistencies and differences. In the same perspective as this, the objective of our project was to consider weak signals as comparable categories based on internal, functional similarities between the two sites. If we can find similarities at this level, we can have more confidence in the possibility to generalize the results. As it turned out, both case studies which we carried out did highlight in an unexpectedly clear way the following three common elements (developed in chapter 6):

-We identified three categories of weak signals common to both sites: technical weak signals, weak signals related to failures of coordination between operators, and weak signals related to underestimation of risks.

-We could locate these in three aspect of the normal functioning in both sites: the management of technical anomalies, the management and coordination of the subcontracting and the method of risk analysis. Shortcomings in these three pillars of risk control, which were supposed to detect and to handle these anomalies before the event, instead facilitated the process by which signals persisted in their weakness in both companies.

-In turn, we could identify three organizational failures of normal functioning having their roots in the structure of both organizations. These were: a defective coordination or a fragmentation between the operational sector and the administrative sector (line and staff), a process of information filtering, and finally a limitation in organizational learning.

The two case studies we conducted showed clearly that the issue of weak signals was neither specific to the four accidents we studied, nor trivial, but was very structural. By digging into normal functioning, we underlined the organizational roots of the formation and the persistence of blockages and filters which make, or keep signals weak and weaken reliability as well.

3.3.1.3 Generalization

There is a tension between the desire to emphasize the full complexity and particularity of an observed social reality (an organization, an event etc.) and the need to generalize by identifying some regularity across different cases, which requires some degree of abstraction. Comparison is not an answer to this tension, but it does enable us to test the transferability of a hypothesis or an idea across at least two case studies.

In the field of safety and more particularly of accident analysis, Pathé-Cornell (1993) is an advocate of the notion that it is possible to transfer the lessons learnt from an accident arising in a very specific context to other industries. Although very specific, an accident reveals pathogenic factors which could be identified in different industries – e.g. complex structure, difficulty to maintain a proactive feedback experience (see sections 2.2.2.1.2 and 2.3.1.2). According to Dien & Llory (2004), such factors identified from a range of case studies can allow us to draw more general lessons from accidents, which are transferable from one organization to another. These factors can be considered as generic and allow a cross-functional and generalizable reading of an accidental sequence

In conclusion, comparison, as a strategy and methodological approach, is an interesting way to formulate, even from two case studies, hypotheses on factors blocking the processing of weak signals, provided that the two cases agree substantially in their findings and conclusions and there is no indication that they are statistical outliers.

3.3.2 Recommendations: a path of change for action-research?

3.3.2.1 Feedback

The first phase of the action part of action-research consists of feedback to the industrial partners. Few researches tackle this issue, despite the fact that it constitutes an essential part of action-research. To Uhalde (1999), feedback is the transmission of a scientific message - characterized by a certain complexity because of the variety of data handled and the multiplicity of the possible interpretations. It is sociological, because it emphasizes the meaning of the data in a social perspective, suggesting different connections and relations between the people in the organization. It sets itself up in contrast to the currently accepted picture of the organization, which can generate a reaction of acceptance or rejection of the message by the industrial partner.

This feedback message is the result of hard work over a long period, carried out according to the requirements of a sociological diagnosis - data collection and analysis need the necessary maturation time for their interpretation. Feedback, according to Uhalde (1999) needs to find a way to describe these facts using theories which make sense for listeners in order to pass on an understandable message in a short time.

The message is presented, but then has to be received by the industrial partner. Two reactions can be observed: acceptance of the results or refusal of the diagnosis. This reaction may vary according to the implications for the partner of the proposed results, as well as according to the capacity of the researcher to explain the diagnosis and the recommendations in an understandable and practical way. To achieve the acceptance of the diagnosis by the partner, it is necessary to find a balance between the comprehensibility and the practical character of the diagnosis, and the necessary rigor to ensure its scientific quality. As will be seen in chapters 4 and 5, there were problems in arranging feedback to the two sites, such that ACIO did not have a full feedback, while that to EDIA ran into a number of the problems which required two rounds of feedback as described in chapter 4.

3.3.2.2 From research project to concretization: recommendations

To what extent are the principles of action-research useful and relevant to improve the safety of an organization? It is a question of energizing an action of change through the research itself and through its results, which requires acceptance of the feedback and internalization of the recommendations on the EDIA and ACIO sites. This has to overcome any defensive reaction triggered by the factors discussed above. The role of the researcher does not consist, according to us, in the proposition of a "set of tools" ready made for change, but in the elaboration of a global methodology or approach to the modification of the organizational factors blocking treatment of weak signals. In this respect the idea is that the sociological diagnosis should perform the function of a mirror held up to the EDIA and ACIO sites, so that they can see their own shortcomings relating to an initial problem. The diagnosis should broaden the way in which the companies look at themselves and enable them to identify weaknesses at the root of the problem and make their own detailed plans to improve, supported where necessary and possible by the researcher. This presents an important challenge to the sites we investigated.

This raises a final question for the thesis. To what extent can we claim that the results and the recommendations are correct or relevant to improve the treatment of the weak signals at the sites? On the basis of what criteria can the site, or the management of the company, accept or reject the results stemming from a diagnosis? We shall bring some elements of an answer to these questions in the chapter about the EDIA case study (chapter four).

In conclusion, this chapter has been a critical presentation of the methodology we set out to use, namely action-research in two case studies. We have placed much emphasis on the data collection through the two viewpoints of accidents and normal functioning. The first tells us about what has not been learned in the past to prevent the accidents, what is being learned now they have happened, and what opportunities are still being missed, all because of the way in which (potentially and actually) weak signals are being handled. The second helps us to locate the causes of this poor handling of weak signals in the normal structure and functioning of the organizations studies. The study was conceived as having an important feedback element which was planned to lead to recommendations and a process of change in the companies, in the tradition of action-research. This phase was limited in practice by the time available for the work and the reaction of the industrial partners to the relevance of the results.

PART 2: CASE STUDIES

4. EDIA case-study

4.1 Introduction

The first case study was conducted on a French refinery, EDIA[21], over a period of five months. It was conducted in three stages. The first phase was devoted to the study of normal functioning, the second phase to the analysis of an accident on the EDIA site. The third one was focused on two feedback sessions set up with the site and headquarters to report to the company on the findings of the first two phases.

The results of this case study are presented in this chapter, composed of the following parts.

4.1.1 Presentation of the EDIA site and accident analysis

First, we will briefly present the EDIA site, by describing three important elements: the activity of the site, the organization, and the role of different operational and administrative departments in safety management. The second part of this chapter will be devoted to the presentation of the results of the accident analysis we conducted on the EDIA site.

First, we will deal with the context and circumstances of the accident. The central event was the occurrence of severe burns to a subcontractor operator during maintenance work on an equipment conducting steam. A Rex was put in place by the EDIA site and the EDIA Refinery Headquarters after this event. The methodology, tools used and lessons learned from this company Rex will be described.

Then, we will submit our own analysis of this accident. Based on our study of internal documentation, interviews and observations, we will define and categorize two types of weak signals present in that accident:

-Problems with the sharing of tasks between subcontractors and the EDIA coordinator in the specific context of the manipulation of an isolating valve, leading to persistent deviant practices

-An underestimation by the subcontractor and the EDIA site of the risk posed by steam.

These two factors constitute weak signals of the potential for the accident because, if they had been detected prior to the event as a threat to safety that could have prevented the accident. We will show in the conclusion of this second part that these two elements were identified during the EDIA accident analysis but were not included in the formal Rex carried out by EDIA. "Lessons

[21] The name of the company has been changed to keep it anonymous.

learned" (in the sense of Argyris) from this accident by the company have been, from this point of view, limited to changes made at a first level of organizational learning.

4.1.2 Normal functioning

In the third part, we will link the data from the analysis of the accident with those from our study on normal operation. Our objective is firstly to identify organizational factors that lie behind the factors we have identified as weak signals in the first part and, secondly, to identify factors which favour the persistence of these signals as weak ones. Three characteristics of the organization of EDIA seem interesting to be studied:

a. **Organizational complexity** resulting in:

-Organizational fragmentation, characterized by a gap in communications and coordination between the line area and staff policy area, and a streamlined segmentation of labor subcontractors,

-Fragmentation of safety management characterized by a distinction between line and staff managing safety, and, within the Safety Management System, a difficulty in integrating safety data from different sources to derive knowledge on potential risks on the site.

b. **A closed model of communication**, characterized by filters in the communication channels. These filters had two consequences:

-Amplification in processing information that fitted into the specified analysis frames

-Blocking of information which did not fit into these frames of information interpretation, with consequent weakening of the message being transmitted.

c. **Single loop organizational learning** limiting the lessons learned and the actions put in place to the technological and behavioural dimensions of the accident, and to reaffirmation of the rules and procedures, rather than making changes of a more organizational nature.

These three organizational characteristics are put forward as the main obstacles to the successful processing of weak signals.

4.1.3 Feedback sessions: contributions and limitations of action-research

The last section will be devoted to evaluating the two feedback sessions that we made during the case study to report on the findings of this research. It will deal with the practical arrangements and, secondly, with the results we presented. They allow us to complete the results we have previously proposed, particularly by analyzing the reaction of participants in these sessions, and evaluating the process of Action Research that we conducted throughout the four years of research.

By combining the data from normal operation and the accident analysis and their consequence for the problem of weak signals, we propose an analysis of the learning system at the EDIA site.

4.2 Presentation of the EDIA site

4.2.1 Structure and operations

EDIA site's main business is the refining of crude oil. It is part of an international energy group, which operates thirteen refineries, of which six in France. The EDIA site began operating in 1970.

Before any treatment of oil, the crude product arrives by boat in the area called the crude oil wharf. Boats offload the oil into one or more pipelines, which supply major storage tanks located in the wharf area. Then pipelines route the product about five km to the storage area of the EDIA refinery. The refining process consists of three main steps:

-Atmospheric distillation. Its purpose is to separate the crude oil, previously evaporated, into a number of products: atmospheric residue, gas-oil under vacuum, kerosene, gas and petrol. During this phase called stabilization, the gases are separated from the petroleum.

-Vacuum distillation separates the heavy fraction produced by atmospheric distillation into a light fraction to be treated in the catalytic cracker. Catalytic cracking allows the conversion of heavy hydrocarbons into lighter products such as gas, high octane fuels gas oils and aromatic flux.

-Finally, once the crude oil has been separated into its various fractions, and processed, the production unit provides blending and shipping of products to obtain a product of specified quality. Tanks store up to 1,200,000m^3 of crude oil, intermediate products and finished products. Products are shipped by sea (28% of finished products), by pipelines (48%), road (20%) and rail (10%). Finished product is delivered to customers of the refinery (Source: DVD of the Prevention Plan 2006, refinery EDIA).

These three areas are closely interrelated because each represents a part of the production chain. The organizational structure (figure 9) helps us to understand both the organization of the business and safety management.

4.2.1.1 Quality department

The Quality department is divided into five sectors:

-Safety service: Management of subcontractors and occupational safety[22], intersite Rex),

[22] This is safety specific to workplaces and the site in general and does not include process safety, which falls under the Environment service.

-Quality service: application of ISO norms, quality audits, and management of some databases related to safety (anomalies and critical events),

-Environment service: environmental management and major accident prevention,

-Inspection service: management of installations covered by statutory regulations, control of static equipments (pressurized vessels for example),

-Health service: occupational diseases, first aid and medical treatment.

The Quality service is responsible for conducting safety management policy based on four main documents:

-Safety management system based on the International Safety Rating System (ISRS),

-Environment management system based on ISO 14001,

-Quality management system based on ISO 9001,

-Inspection management system .

Each manual is managed by a quality department manager who aims to ensure compliance with its requirements and a regular review of its content.

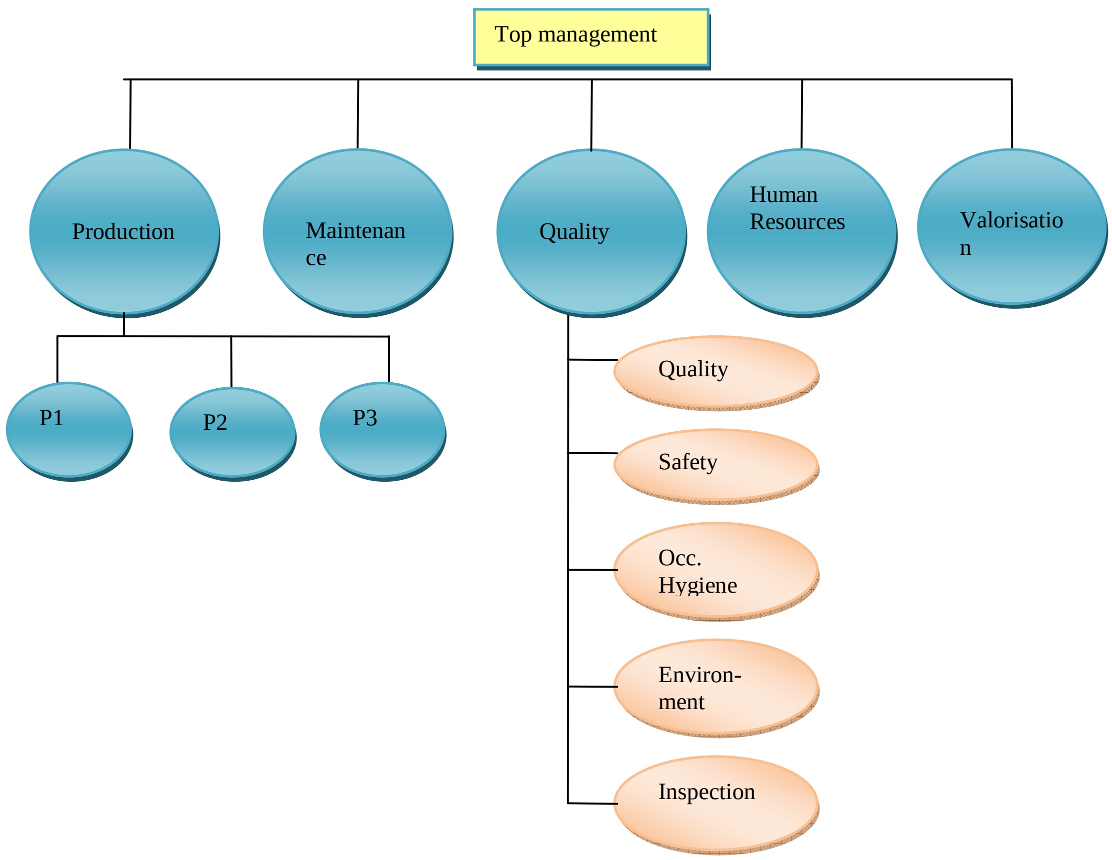

Figure 9: EDIA organization chart.

Legend: P1, P2 and P3 refer to three production units.

4.2.1.2 Subcontractors

Maintenance (see figure 9) comprises curative treatment (short term repair), preventive maintenance (medium term) and management of outages (long term). It is carried out by sub-contractors and controlled by EDIA staff (350 EDIA employees, 400 sub-contractors). Subcontractor management is formally regulated by a policy which specifies that:

-The subcontractors must have a safety license to work on the EDIA site,

-They must accept, complete and sign a Prevention Plan document which specifically indicates the company expertise and dangerous activities they may carry out,

-Finally, the company must be registered in the directory of subcontractors that is to say in the computer system for issuing work authorizations and permits.

Once the subcontractors have received a contract and work authorization, their operatives must be trained in safety. This training is provided by the safety department and deals with:

-Dangers inherent to the EDIA site and activities,

-Emergency Plans: the Internal Operation Plan (for an accident on the site) and Specific Response Plan (in the case of a major accident),

-Specific danger areas,

-Work equipment,

-Rescue.

EDIA ensures safety upstream of the intervention but also downstream by the checking of results achieved and the formalities of obtaining, holding and surrendering a work permit.

4.2.2 Safety management

The EDIA refinery Safety Management is guided by two Safety Management System manuals:

1. The **Major Accident Prevention** policy which includes:

   -Compliance with laws and regulations on classified installations for environmental protection (ICPE in French)

   -Training and qualification of personnel: systematic review of professional skills and attention to safety; safety training of all personnel (contractors and EDIA personnel)

   -Identification and control of risks

   -Operational control i.e. operations and maintenance of operational units

   -Control of the design and modification of units

   -Design and preparation of emergency plans

-Rex management: sharing and dissemination of lessons learned from critical incidents with all EDIA refineries (the details of Rex process will be presented in the second part of this chapter) (Source: Manual of the Safety Management System, refinery EDIA Version June 2006).

2. **The Safety Management System** is a guide which answers directly to the requirements of the International Safety Rating System (ISRS). Its aim is to measure and improve the performance of the company's safety management. It consists of the twenty standard elements of ISRS (Source: Manual of Safety Management System, EDIA):

Leadership and program administration, Management training, Planned inspections and maintenance, Analysis of critical tasks and procedures, Analysis of accidents and incidents, Works task observations, Emergency preparedness, Regulations and work permits, Analysis and statistics of accidents and incidents, Employee training, Personal protective equipment, Health and industrial hygiene, Auditing systems, Engineering and change management, Individual communications, Team meetings, General promotion, Hiring and employment, Purchases of goods and services, Safety outside of work.

For each element, the EDIA refinery has appointed a responsible person. He or she must implement the necessary resources to achieve the objectives of his/her element (on of the 20 elements described above). For example, the Quality service is responsible for promoting compliance with and enforcement of this standard and organizing audits (conducted by an external body every two years) to assess the result that the site achieves.

The existence and application of these two manuals reflects a distinction between an administrative management and an operational management of safety (Major Accidents). This gap forms one of the weaknesses of organizational learning at the refinery of EDIA, which will be discussed in the more detailed analysis in part III of this chapter.

We turn now to the analysis of the EDIA accident.

4.3 Accident analysis: towards a definition of weak signals

The second part of this chapter is devoted to the accident analysis we carried out and the results obtained. For the analysis we conducted seven interviews, with the head of maintenance department, quality department manager, the head of the production unit where the accident happened, two employees of the subcontractor involved in the accident, the EDIA coordinator involved in the accident, and the safety service manager. Several visits to the accident site were carried out and finally we reviewed the documentation related to the event: the accident report, the Rex notice and fault tree analysis. We present these results in three stages:

-Description of the event: context and circumstances of the accident,

-Analysis of Rex notice produced by the site and by the EDIA Refinery headquarters,

-Definition of two weak signals relating to the accident and three organizational factors which, according to our interpretation, prevented their treatment.

4.3.1 First part: from the accident to lessons learned

This first part deals with the analysis of the chosen accident in terms of weak signals. To do so, we analyzed the way in which the site mobilized its tools and methods to detect what had been the early signs of the accident and to learn how to reduce the effects of the accidental sequence or to avoid the event altogether, in order to improve their learning abilities based on the past experiences relevant to the accident.

4.3.1.1 Back to the circumstances of the event: facts and interpretation

This case study has enabled us to analyze an accident by combining several approaches: the reading of analysis documents produced by the EDIA site and headquarters, and interviewees perceptions. Our objective is not to look for mistakes or errors but to identify the different elements that led to the accident. We first focused on the chronology of events as it had been reported by the interviewees.

We used the ECFA+, as an experiment method (during the second feedback session; this point will be developed in section 4.5), which aims to produce a sequential description of an accident (see appendix 8). It allows an investigator to identify all the events that led to the accident, place them in chronological order and connect them causally. The links between these events are audited to ensure that they can explain satisfactorily the accident sequence studied. Identified events may be supplemented by conditions under which the events of the accident sequence occurred.

4.3.1.1.1 The context of the accident: a huge maintenance campaign

A maintenance campaign was being undertaken by production unit 3, after a number of anomalies on the system had been observed. It started several weeks before the work in which the accident occurred. After a diagnosis, the production unit noted that some steam lines, including that on which the accident occurred, were obstructed by plugs of limestone. Steam line blockage is a recurrent anomaly, for which maintenance had already been undertaken earlier. To solve the problem on the specific steam line, two main tasks had been planned: cutting the line near the limestone block, and cleaning the line by using high-pressure cleaning. The blockage of the pipes was therefore treated as a technical anomaly to be resolved:

« So it was a problem that had existed for several days?
Several days or even several weeks…. Many interventions had been made to unblock lines. It's a problem of coping with the hard water in the pipes (…), and the scale had formed blockages as hard as stone» (Unit production head)
« So that I can understand, could you explain to me what is a campaign?
A campaign is a group of actions. We had observed several leaks, and this operation was one operation within this campaign. The leaks had two disadvantages: a loss of money and more consumption of materials. The later we react to this, the more significant the work to be done is » (Head of maintenance department)

4.3.1.1.2 Preparation work

The two tasks of planned maintenance work were prepared during a coordinated meeting involving operators, maintenance staff, preventionists and contractors. On the basis of our analysis, we have identified and classified a number of safety barriers, put in place to ensure the safety of the installation and the operators. The ones relevant to this accident are the permit to work and the role of the coordinator.

First, the interviewees placed the incident in the context in which the work was done on the site. The EDIA site has put in place a permit to work system (PW) in which the work to be carried out is specified, together with the safety measures required by the EDIA site and those provided by the contracting company to reduce the risks identified. Each production unit manages the work planned during daily coordination meetings in order to avoid the risk of accidents related to coactivity. During that meeting, work permits are issued and validated by the day foreman responsible for the works, and Work Authorizations – the only documents allowing companies to work within the refinery - are given out. They must be signed by the relevant shift supervisor.

Two distinct work permits were issued for carrying out the on-site maintenance work during which the accident occurred:

-The cutting of the line by company 1, on day 1

-The cleaning of the line by company 2, the day after.

Second, these maintenance works were supervised by a works coordinator of production unit 3. He was responsible for the delivery of the installation for the work; that means, in the context of this operation, isolating the installation by closing the isolation valve upstream of the line and decompressing the line by opening the purge-pressure equipment (2 bars). This provision enabled the contractors to work safely.

4.3.1.2 The conduct of the maintenance work: work permit exceeded

The interviewees described very clearly the sequence of events. On the morning of the accident, the works coordinator and company 1 went to see the place where the work had to be carried out. Having safely isolated and handed over the installation to the contractor, the works coordinator authorized company 1 to work on the equipment. In the afternoon, company 1 began to work. The fitter proceeded to cut the line, as the work permit stipulated. Almost unanimously, the interviewees confirmed that the PW had very quickly been exceeded. After having cut the line completely, the fitter from subcontractor 1 tried to locate the limestone block in the line and to clean it out:

« So the guy cut the line, looked inside and saw some sand. He said to himself that the blockage couldn't be far away. He put the steam back on, opened the valve, but the steam didn't come through. He tapped along the line, giving it little blows. He got back on the scaffold convinced there was no danger. He walked in front of the cut end, and that was the crazy thing, he walked in front of the cut pipe with the valve still open. He hadn't expected that. He underestimated the risk. He knew of the risk but he walked back in front to try to understand what was happening. In fact he was looking for where the blockage was, feeling the hot spots and the cold spots » (Contractor)

« So the works coordinator isolates the line and depressurized it and handed it over. Company 1 cut the cold line and saw that there there was a lime scale blockage. On the Work Authorization was written that he should do the cold cut and that the cleaning should be done by company 2. There wasn't the same risk analysis at the back of that. So he got disturbed a bit of the blockage at the level of the cut and thought to himself that it would be difficult for company 2 to do the cleaning»

"Why would that be difficult for company 2?"

« Because they were going to use a plumber's snake, a sort of arm which can apply pressure, but which has to be inserted into the pipe. But, given where the blockage was situated just at the point of the cut, he thought that would be difficult. So legitimately - actually not legitimately – he tried to remove the blockage. He could feel the pipe was hot further up, so he knew the blockage was there. He opened the valve, he put the equipment back into service in the end, even though that was the responsibility of the works coordinator» (Head of production unit)

This was, according to the interviewees, a first deviation from the rule.

To be sure that the blockage was still present in the line, the fitter put the equipment back in service so that the line would pass steam. After having tried to contact the works coordinator and found him unavailable, because he was supervising other works on the site, he opened the valve himself to continue his diagnosis. This was the second transgression of the rules.

Finally, the fitter stood (or walked) in front of the cut line to observe any movement of steam. By the combined effect of the pressure and hammering on the line, the line suddenly unblocked and released steam and hot water. All interviewees agreed on the fact that the second-degree burns on the fitter from the steam were the central event of the accident. The injured fitter was taken to the infirmary and then to hospital.

Beyond the facts presented, the interviewees raised an interesting issue. Firstly, they did not question the rule prescribed by the EDIA refinery; any subcontractor must operate in strict compliance with his work permit, which indicates the tasks to be done and the necessary safety measures for the work. However, the interviewees state that the contractor, shift manager of company 1, had a long work experience and knew this production unit as well as the work in progress very well. Exceeding the strict work permit can be thus understood as follows. The fitter wanted to:

-Evaluate the situation experimentally and informally (as opposed to the written, formal analysis of the anomaly). Interviewees use a vocabulary related to the senses. The fitter "feels" the line to find the hot spots (flow direction) and cold spots. Then "touches" with his hands the blockage, noting its "brittle" texture.

-Solve the situation. The words of the interviewees clearly indicate that the fitter has knowledge of the facility and the process of isolation - he knows how to open the valve and put the equipment back in service to attempt to get the steam flowing and confirm the presence of limestone blockages.

-Anticipate the cleaning operation in its entirety. Recall that this particular work is part of a larger campaign initiated by the production unit in which the victim is used to working. So, he possesses information which goes beyond the scope of his own task. Anticipating the work of company 2, the fitter attempts to improve the preparation for the work of that company. Although his work is limited to cutting the line, if the line has not been cut in the right place, which is what he tries to evaluate, then his task will have been poorly finished in a technical sense and in relation to coordination with company 2.

Exceeding the work permit would mean both a personal willingness to perform his task satisfactorily, but also to allow proper coordination with company 2. We will see later how this "violation" reveals deeper safety dysfunctions, including underestimation of risk.

4.3.2 Second part: how does EDIA refinery learn from the accident?

4.3.2.1 Accident analysis

This event provides an excellent case study of the resources allocated by the EDIA site to analyze accidents and draw lessons from them. Reading the interviews and documentations, we observed two levels of accident analysis, an in-depth analysis by the EDIA site, and an analysis conducted by EDIA headquarters. We identified the following stages:

-Information reporting,

-Analysis of data,

-Corrective and preventive actions,

-Lessons learned from this event.

Learning from past events, especially accidents or incidents, requires a reporting of the facts. Under the decree of May 10, 2000, the EDIA site must put a Safety Management System in place, including, among other tools, a Rex. The analysis of the accident showed the workings of this system, in which we will trace the following major steps. We propose to represent the Rex process schematically as in figure 10:

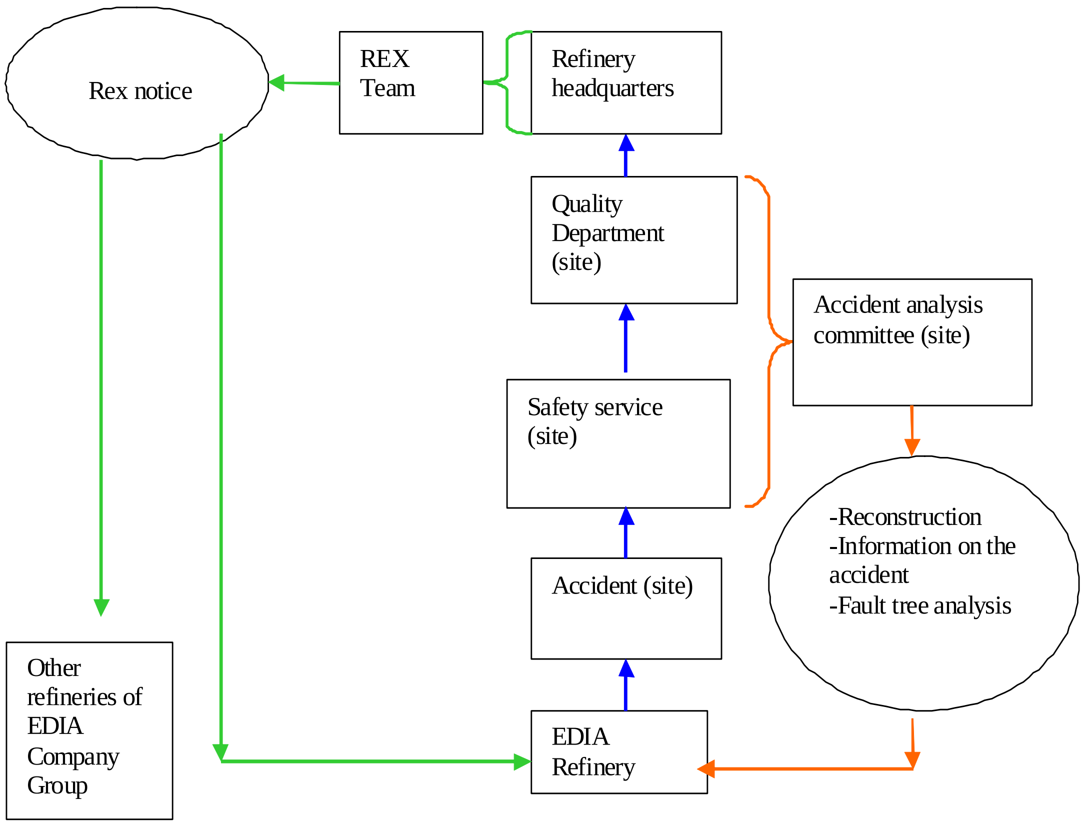

Figure 10: EDIA Rex process.

Legend: blue, information transmission. Orange: analyses and diffusion of EDIA. Green: analyses and diffusion produced by headquarters.

Based on the data collected, we have identified the following steps:

-Detection/Reaction. After the accident, information was firstly reported to the safety service (by a witness), and to the quality department. The latter transmitted the information to EDIA headquarters,

-Transmission of the information. The recipients of information (quality department) shared the information through two channels:

-Site: quality department sent two documents to the whole refinery: "Safety Flash" and Preliminary Notice of accident,

-EDIA headquarters Rex Group sent a Safety Alert to all EDIA refineries,

-Treatment: two groups for analysis of the accident were put in place. On the site, an accident analysis committee was composed of representatives of production unit 3, the safety service, maintenance, subcontractor, witnesses and top management. This analysis was intended for site staff. At headquarters, a team was devoted to a Rex analysis on the basis of data supplied by the site. This is meant to share the information with all EDIA refineries.

The next sections focus on the analysis committees; we will raise two issues:

-Locally, the procedure and method used for the analysis of this event,

-At headquarters, on what criteria this event was chosen for a Rex.

4.3.2.2 Selection criteria and filters in information treatment

4.3.2.2.1 Local accident analysis: three steps

First of all, the accident that we have analyzed was rated severity A[23] by the EDIA site. In such a case, a particular treatment procedure has to be implemented:

-**Data collection** consisting of reconstruction of the event to get as much information as possible about the circumstances of the accident,

-**Identification of causes**: a fault tree analysis (appendix 2) conducted by the accident committee (figure 10) allows the identification of the origins of the accident,

-**Information transmission**: EDIA site sends out an "Avis d'Accident" (Accident Notification) and "Info Sécurité" (Safety Information Sheet) to all on the site to give staff the site information and elements about the circumstances of the event,

-**Treatment and solutions**: the site works quickly to find appropriate measures to solve the immediate and deeper causes that led to the accident.

In this case, the interviewees very quickly spoke about a difficulty in understanding the circumstances of this event.

The steam pipeline, which was handed over to the contractor, should be returned to service only by the works coordinator. During analysis by the accident analysis committee (see figure 10) at the site, it was discovered that the subcontractor had manipulated the valve to return it to service. However, sub-contractors, except in certain cases, may not manipulate the process valves. Only EDIA operators are allowed to do that.

In addition, a fault tree analysis (appendix 2) built by the accident analysis committee identified as central event this problem of the process valve being manipulated by subcontractor 1, labelled as an exceedance of his work permit. The fault tree only identifies technical, behavioural and related procedure compliance causes. Items concerning the work organization, that is to say the

[23] According to the gravity scale established by EDIA, gravity event A is serious, B moderately serious and C minor gravity. The accident was classified as serious (A) because a worker of the subcontractor got second degree burns requiring hospitalization and work stoppage.

procedure followed by project coordinator in handing over the work area and the concrete development of the intervention, are not addressed.

Finally, the EDIA site investigation limited itself to the conclusion that the accident was a question of poor discipline and compliance. However, this accident and the way it was investigated on site led us to raise two further questions. The first one is related to the allocation of tasks, characterized by a blurring of boundaries between the tasks of the EDIA project coordinator and subcontractor 1, in handling an isolation valve. Although the regulation clearly states that subcontractors may not manipulate "process" valves (they belong to, and are the responsibility of EDIA and its operators), deviations, sometimes tolerated by the line management, appear to exist. The accident has revealed some informal deviant practices, which were not confined to this accident. Second, although the contractor is experienced and knows the equipment, why does he stand in front of the cut line? How is risk assessed not only by the subcontractor during his work, but also by EDIA site? We return to these below.

The sections that follow deal with the accident analysis performed by the Rex team (see figure 10). In what follows in the next section we describe the main steps of the Rex process applied by EDIA Group Headquarters within each refinery.

4.3.2.2.2 Refinery headquarters: Rex process

In parallel with, and in addition to the local analysis, EDIA headquarters set up a Rex team. It consisted of four people, all devoted to analyzing the events that occurred in EDIA refineries. This Rex process performed by the Rex team is divided into the following stages. Initially, information that an accident has occurred is transmitted from the local level (a refinery) to EDIA headquarters as explained in section 4.3.2.1. Here, information was received in this case in two stages: firstly the quality department called the Rex team immediately in order to deliver the first information – that there had been an accident with second-degree burns leading to hospitalization. At a second point in time (four days later), an e-mail was sent by the safety service to the Rex team to complete the first report. Based on these facts, the Rex team decided to initiate a Rex process on this event.

The Rex team selects only events rated 4 and 5 in their classification to put the Rex process in place (which refer to severity A according to EDIA refinery scale). But on the basis of more qualitative criteria than just severity (namely, frequency of an event, theoretical interest and interest as example[24]), the Rex team can take into account events rated from 1 to 3 by a refinery and put a Rex process in place for them.

The Rex team decided to put a Rex process in place in this case because of two criteria:

[24] These criteria are not explicitly written in the process of Group Rex, but they were cited by a member of the Rex team, in an interview conducted in September 2007.

-The EDIA refinery rated the event severity A,

-The Rex team observed that, over the past year, there had been frequent accidents, one of whose causes was related to compliance with the procedure to manipulate valves, involving the allocation/sharing of responsibilities between operators and subcontractors.

The interest of the Rex lies in the deeper analysis it provides, and in the sharing of lessons learned with other EDIA refineries. Like the EDIA site accident committee, the Rex team identified as immediate and underlying causes the lack of compliance with the work permit and unauthorized operation of the isolation valve. A "safety alert" form was transmitted to other refineries, followed several months later, by a Rex notice (appendix 3).

4.3.2.3 Depth and timing of preventive and corrective actions

Both the analyses conducted by the EDIA accident committee and the GPREX team at headquarters resulted in recommendations on several levels and in different time scales, see figure 11.

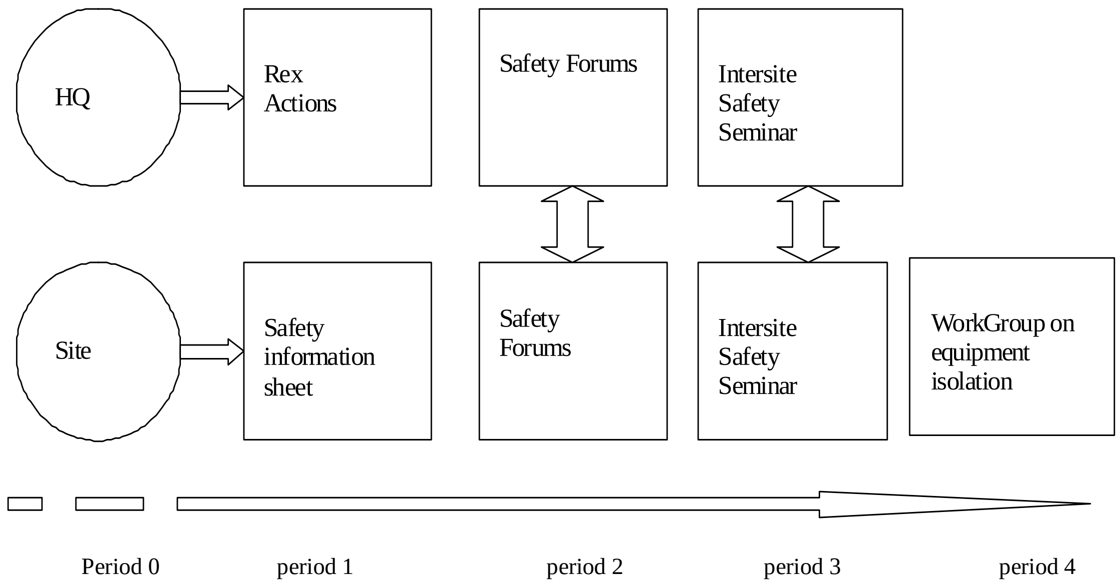

Figure 11: Actions put in place after the accident EDIA.

4.3.2.3.1 Immediate actions for direct causes: step 1

The action that followed the accident analysis conducted by the EDIA site was first directed to company 1. It consisted of a reminder about:

-Compliance with work permits,

-Compliance with procedures current on the EDIA site (particularly valve manipulation).

The subcontractor company itself broadcast the messages to its employees by setting up safety meetings.

4.3.2.3.2 «Middle term » actions for deeper causes: steps 2 and 3

In a second step, the work done by the EDIA refinery and the Rex team generated two actions during which the issue of handover of plant, identified as an underlying cause of accidents, was discussed.

1. **Thirteen "safety forums",** run by site EDIA management, were organized for staff and the day shift. They dealt with the following issues:

-A reminder of the principal safety rules, like the smoking ban,

-Compliance with the procedures and rules on the site,

-The repetition of comparable negative events at work involving plant handover.

EDIA showed through these initiatives a capacity for information transmission and decisions about prevention among employees and the implementation of immediate actions to resolve the problems identified. This action was doubly good because it was an initiative involving both the refinery and EDIA headquarters.

2. **Plant handover** was also an issue addressed during the biannual safety seminar. This seminar brings together all EDIA refineries. It is meant to exchange topics of discussion related to safety. Again, plant handover was shown to be an important central theme, relevant to maintaining or threatening the personnel and facilities safety.

4.3.2.3.3 Workshop on equipment lock off: Step 4

Finally several interviewees referred to the re-launching of a working group on plant handover and particularly the pipeline lock off procedure:

> *«Finally we put in place actions to prevent a repetition. In parallel, but not directly linked to the event, a working group on pipeline lock-off procedures was launched. We thought of putting locks on the valves. But I repeat, that had already been initiated beforehand. That working group had to produce its results in June and it was working to put in place homogeneous practices across the site. Before there had been different ways of doing plant handover, particularly for the pipeline lock-off. Not for the electric lock-off, that had been sorted out There were three working groups: one for isolation, one for tagging of equipment and one for operation of the valves But I repeat, that had been initiated earlier»*
> *"Why ? "*
> *«Because we had already had problems in this area and on other sites. So we wanted to harmonize the practices» (Quality service manager)*

Thanks to this working group, the EDIA refinery did identify one of the causes of the accident, namely the ambiguity or blurring of the boundaries separating tasks between EDIA operators and contractors in handling the isolation of valves: The need to clarify these practices, and hence the procedures, would be one way to solve this "ambiguity". The recommendations of this working group were directed towards three aspects:

-Clarify practices and roles of operators in handover of the equipment. These roles should be formalized in a procedure,

-Reinforce the safety of the plant handover, as was already the case with electrical equipment lock-off, with a system of cabling and chaining,

-Harmonize practices between production units of the site.

These three actions are definitely positive and effective ways to solve the main problem identified by working group, namely the blurring of professional boundaries between the EDIA coordinator and the subcontractor. But are they sufficient?

4.3.2.4 Limitations of Rex

We have three reservations about the effectiveness of the actions proposed by the working group and Rex team, and the actions mentioned above.

First, accident analysis emphasized the recurrence of the steam line obstruction, due to blockages of limestone, which resulted in a major campaign of cleaning. Limited access to data does not permit us to be definite about the following supposition; but, it seems worth raising as a question. The maintenance campaign was a positive action meant to solve the problem of steam lines blocking. However similar maintenance works had been undertaken earlier to remove the limestone blockages. So the question could be raised whether these repeated maintenance interventions were the best way of resolving the problem of blockages in the long term. Would design changes (whether to the steam system or to the preventive maintenance plan) not have been worth considering as a corrective action which could have solved the problem more efficiently? The lessons learnt from this accident could therefore be seen as somewhat limited.

The second reservation concerns the blurring of professional boundaries. Firstly, the working group identified well the problem between the EDIA works coordinator and subcontractor 1. Given the complicities between these two operators, would locking off the valve have been enough? Would the subcontractor not simply have been given the key to open the valve after gaining approval from the EDIA works coordinator? These questions remain unanswered because we do not have sufficient data to answer them. However, we can assume that the proposals of the working group could come up against the realities of work. By identifying the issue of the blurring of professional boundaries, and therefore of complicity between the EDIA coordinator and the subcontractor, the working group also identified an area of uncertainty, beyond the control of the line management, and characterized by the construction of autonomous social relations between operators, which have a life of their own and are hard to change. The actions of the working group can then be interpreted, we believe, as a means to remove or at least regain control over the autonomy built between the EDIA coordinator and the subcontractor. Would that succeed?

Also the working group did not address the issue of the professional boundaries between subcontractor 1 and subcontractor 2 (who had to clean the steam pipe). Although the working group identified the work permit exceedance by subcontractor 1, it did not raise the issue of the relations between the two subcontractors and the potential reasons for exceeding the work permit: was this initiative taken after an informal agreement between the two sub-contractors? Was it an initiative only of subcontractor 1 (as we proposed in section 4.3.1.2)? Was it an attempt by subcontractor 1 to prove he could have done the whole double task? What was the role of the EDIA coordinator? Again, these questions remain as suppositions, but we believe they question the very principles of division of tasks in the work of maintenance. We return to this point in section 4.3.3 of this chapter.

The third reservation concerns risk perception. We noted that the fitter of company 1 stood in front of the cut line without taking any precaution in case hot water or steam came out. This indicates an individual underestimation of the risk of steam under pressure. The working group indicated the need to reinforce the closure of isolation valves by systematic lockout to prevent another accident caused by the reopening of the valves without the agreement of the EDIA works coordinator. This was already standard practice to prevent unauthorized operation of electrical equipment, which seems to indicate that steam may have been underestimated relative to electricity also by the EDIA site. Neither the analysis of the accident nor the Rex notice identified the problem of the perception of the risk of steam.

Can the analyses conducted by the EDIA accident committee and the Rex team, and the actions taken (from period 1 to period 4), solve the problems in depth? We turn to that question in the third part of the chapter, which proposes to define two weak signals of the potential accident that we have identified.

4.3.3 Third part: two weak signals known & identified but not treated

In the first part, we analyzed the Rex created by the EDIA site following the accident. Our analysis identified two factors which, although identified in the accident analysis as signs of deteriorating safety, were excluded from the formal analyses and corrective and preventive actions. These data are recurrent and qualitative but are the manifestation of a dysfunctional organizational safety.

1. The segmentation of maintenance operations and tasks between the EDIA coordinator and subcontractors, and between the subcontractors themselves,
2. The risk associated with steam was minimized or underestimated

These two aspects represent two weak signals of the accident whose characteristics are further analyzed in the next section.

4.3.3.1. Complexity of works organization: what consequences for safety?

To understand the issue of the blurring of boundaries between professional subcontractors and the EDIA coordinator, we studied the conditions under which these practices have emerged.

4.3.3.1.1 Segmentation and rationalization of maintenance operations

First, the interviewees raised the question of the complexity of the work permit procedure which is witness to an increased complexity in carrying out maintenance works. As we have already indicated, maintenance work is supervised by an EDIA coordinator who is responsible for the isolation of the installation, handing it over, and opening the isolation valve when the work is completed. In this case the work was to be done by two subcontractors: company 1 to cut the pipeline and company 2 to clean the line. Why do two work permits have to be issued for the completion of this work? According to our information, EDIA sees this in the following way. The site uses specific technical skills that are held by different subcontractors. Among subcontractors under contract with the site, there were companies specialized in metal cutting and companies specialized in industrial cleaning. They chose one of each to implement this intervention because each of them had the specific expertise sought by maintenance department. This segmentation of maintenance seems to show a rational point of view about the organization of work, but can cause unexpected and unintended “boundary” effects.

Secondly, the procedural organization of maintenance imposes strong constraints on the way the work is carried out. The work permit clearly and strictly defines the tasks to be performed by the subcontractors. However, the fitter of subcontractor 1 is a professional, according to the interviewees, and has a broad expertise - which is why he was legitimately asked to perform the work of cutting the pipeline. Some of the interviewees indicated that the framework of the work permit is then particularly constraining because it does not recognize and allow room for that broader expertise to be used, which can lead to undesired effects:

> *"If we always ask people to strictly apply the rules, it rules out a part of their expertise, namely their ability to adapt to unforeseen situations? So what do we do? We must leave people room for their creativity and we need people in this site who can improvise"(Safety service).*

The way in which tasks to be performed under this maintenance work are formally (and apparently rationally) divided up and allocated to different subcontractors, provides the background against which the development of deviant practices and the blurring of professional boundaries takes place, vertical blurring of authority between the EDIA coordinator and subcontractor 1, and horizontal blurring of professional boundaries between the subcontractors. We are not saying that the current divisions are incorrect, but we do point out that the principles for segmentation of the tasks have so far been questioned neither in the analysis of accident conducted by the EDIA site, nor in the Rex form.

4.3.3.1.2 Informal adjustments to maintain the production rate

The division of tasks between subcontractors and the EDIA coordinator, as we have seen, is regulated by the work authorization procedures and the work permits (the formal rules). But any such relationship is also subject to many informal rules. These are developed through, and favoured by collaborations between EDIA operators/coordinators and contractors, as part of their tasks, and can help overcome the limits of prescribed rules. An adaptation or reinterpretation of these formal rules can keep the system - here the maintenance work - running when a strict interpretation of the rule would no longer allow that. These informal adaptations are not observed or controlled by the formal rules and therefore by the line management. Terms such as "dead zone" or "no man's land" (Maintenance Department) are used to describe these grey areas, which shows that these interfaces between EDIA operators/coordinators and contractors are not governed only by prescribed rules and, by extension, they can be defined by rules and practices that can be hidden from the line management.

How do these rule adjustments arise?

> *"What the incident demonstrates is that maintenance [subcontractors] and operations work together all the time, they plan the work together. Their activities are linked ; they do things together. One does the work of the other and vice versa" (External Company).*

Despite a clear prohibition on subcontracting firms to manipulate process valves, they know how they work. As we stated in part one, this expertise and their knowledge of the production unit and the problems requiring interventions allow subcontractors to share their practices and skills with the EDIA coordinator. In the absence of the latter, contractors can pick up the task. These practices are known and tolerated not only by operators themselves but also, in some cases, by EDIA management.

4.3.3.1.3 Organizational and environmental blockers

Finally, we add two elements which, more indirectly, can reinforce these informal practices: risk perception and production pressures.

According to an interview with a key player, one of the safety staff, he had given a warning of this threat to safety and had been, according to himself, repeatedly ignored:

> *"But this is not the first time I've seen such breaches of safety rules. I have said many times to my superiors that he [the contractor] was acting thoughtlessly "(Preventionist)*
> *"In addition I have said ... I can see it happen. I have told my superiors but, you know the line management!! ... The guy was burned so he was not further punished.... but the problem is, if we never impose sanctions, the guys couldn't care less… if there is no stick behind them ... We are on a Seveso II site so we can't just let them get on with it. There is a risk to yourself, others and the environment. Things can soon become a big problem."(Preventionist))*

The remarks of this "whistle-blower" lead us to the following observation. First, the safety coordinator attempted to transmit a message. It was based on his expertise and field experience, but the warning signal sent to his superiors was in the form of an observation, a verbal message which did not follow the formal channel of transmission of information - such as audit does. He had repeated that verbal message several times, which he saw as being the way to give importance to the alert. However, what appeared to be a warning, a strong signal as far as the safety coordinator was concerned, was ignored by his superiors, so the signal remained weak and had no impact.

Why was the message blocked at its reception? It would appear that the message did not contain enough tangible evidence to convince the supervisor of this preventionist that it was a credible threat to safety. It would seem that informal strategies of information communication do not find any "receiver" in a highly formalized system in which the tools, the channels of transmission and decoding of information categories are fixed in advance and relatively closed to change. But two questions remain:

1. Workplace audits are designed to detect whether the work being done complies with the work permit. The item "work" on the form is used to indicate if the PW has been signed and the work matches the specifications (for the details of the specifications, see Appendix 4). However, this form does not provide specific space for notification of an exceedance of the work permit, unless it is specified in the space left to the auditor for "comments". If this preventionist chose to transmit his message through an informal information channel, can we conclude that he considers the channel of the audit form is ineffective for reporting a rule violation and more specifically someone exceeding the work permit? Or is he being wise after the event and magnifying in his own mind what he did before the accident happened?

2. Does the line management, responsible for receiving the message and addressing anomalies (implementing corrective and prevention measures) take enough care to give credance to information coming via formal channels and so encourage their use as a tool that can be used to

cover and detect all types of anomalies? On the other hand, do they pay enough attention also to informal channels? We will try to provide some answers at the end of this chapter.

Secondly, production pressure may, in some cases, focus the priority on production and relegate safety to the background:

> *« So the project coordinator has some autonomy in his area. He works in a crossfire of priorities: the yield for company 1, efficiency for EDIA (the work must be fast and good) and safety. So it is true that it is a balancing game" (Subcontractor).*

To meet the objectives fixed by the refinery, exceeding the strict boundaries of the work permit may be considered as a solution, because it would meet both the requirements of the EDIA site, those of the subcontractor, and also the requirements of a "job well done" which is important to the operator. These two elements provide some additional explanation for the persistence of the deviant informal practices around the manipulation of the isolation valve.

We hypothesize that the exceedance of the work permit comes not just from a desire to violate the rule, but in order to create flexibility in the strict context of this work permit, to create a space for professional autonomy, to regulate the informal practices between subcontractors and the EDIA coordinator, to respond to the constraints imposed by the coordinator, and to carry out the maintenance work in a minimal time.

4.3.3.2 The underestimation of the risk of steam

This section addresses the second weak signal from this accident analysis, which we have called the underestimation of the risk of steam. Four elements allow us to assume that steam may have been underestimated as a risk.

Firstly, as we mentioned briefly above, the fitter of sub-contractor 1 decided to clean the steam pipe himself. The accident committee identified the fact that the fitter, despite his expertise, did not evaluate the risk on his own initiative. He wore no protection against a possible steam escape and, by positioning himself in front of the cut line, he took an even greater risk.

Secondly, the fluid being transferred by the pipe work on which the accident occurred was considered according to the EDIA risk analysis system to be simple and not dangerous:

> *"At that time, there was no work procedure that defined the equipment handover [for this sort of equipment], because steam was considered a simple network ....".*
> *"What does that mean, "simple"?*
> *"That means, not complex ... there is no real danger, especially as steam, if it escapes, disperses into the environment "(Production unit manager)*

Thirdly, working on this type of equipment did not require the EDIA refinery to:

-Write a procedure for locking off the equipment,

-Lock off this equipment mechanically (with a padlock and a key).

The limited time for the analysis of this accident did not permit us to study in depth the full reasons behind the risk analysis developed for this type of equipment and to understand fully why steam was not considered dangerous. We simply observe that the risk was minimized or underestimated at both levels:

-The fitter stood in front of the open line to locate and remove the limestone block. We can therefore query his knowledge about the risks involved with steam, but also the training he received, which could have prevented the burns he suffered.,

-The site did not implement any precautionary procedure for the work, nor did it require locking off of the facility.

This seems to show that the risks assessed by EDIA were focused on the dangers related to oil and its products - leaks, fires or explosions – which may have weakened, in comparison, the consideration of other risks associated with fluids such as steam, which can inconceivably result in major accidents reaching beyond the factory gates. But the incident showed that the equipment on which the accident occurred does contain risks – the high temperature and pressure of the steam and condensate – albeit only for one or a few workers on the plant. It was only after the accident that steam was seen as a potentially dangerous fluid, requiring the establishment of technical barriers – lockout - and organizational barriers - a handover procedure which was written and followed.

Finally, the perception of the risk of steam seems to be absent as a topic during the analysis of the accident and does not appear in the recommendations of the Rex notice prepared by the Rex team. There appears to be a reluctance of the site to recognize, and above all to include that underestimation of the risk of steam in a formal Rex notice shared with other refineries. This corroborates the idea that an organization can gradually build a cognitive and cultural blindness, hindering the perception and treatment of some risks.

In conclusion, we identified two weak signals of the accident: the blurring of boundaries between the contract principal (EDIA) and the subcontractor's tasks and between the two contractors, leading to a weakening of safety; and the poor risk assessment of steam. These practices were related specifically in this case to the manipulation of an isolation valve installed on an installation perceived as simple because it was 'only' carrying steam, a fluid considered "not dangerous." This weakness of the signals was the result of two underlying factors:

-The complexity of the task organization and allocation of work permits, splitting up the actions and tasks between EDIA and the contractors, and between the two subcontractors, which is exacerbated by the production pressure prevailing in maintenance operations, which has to be balanced with safety, which in turn leads to informal practices and adjustments between operators to ensure the implementation of interventions, in this case by exceeding the work permit. In addition several warnings from the safety auditor were ignored.

-An underestimation of risks, especially of steam, by the site and the fitter of the subcontractor.

These two weak signals reveal organizational dysfunctions in safety management: deviant practices and poor risk assessment. They can be as the evidence of a period of incubation of the accident encouraged by the other two factors outlined above: the increasing complexity of work organization and construction of beliefs based on technical knowledge, leading to blindness to other risks.

Although well-known and identified in particular by the working group on equipment isolation, these signals did not benefit from analysis or a deep treatment within EDIA. The Rex notice and accident analysis remained reactive and based on the technical and procedural events. They come after a major accident and reveal the difficulty EDIA has to integrate organizational information into them, which consequently reduces the opportunities for learning and resolution in depth of the problems identified.

The following sections present the results from the study of normal operation at EDIA. They are intended to broaden the conclusions from the analysis of accident and to identify organizational factors enabling us to better understand the limitations of the Rex.

4.4 Organizational complexity: consequences for weak signals detection and treatment

The first two parts of this chapter have described the EDIA accident analyses, set up following a significant event that occurred at their refinery.

The Working Group, re-launched after this accident, did identify plant handover as a central factor in maintaining personnel and installation safety. However, the lessons learned from this accident were only technical and procedural which, we believe, will not allow a full enough understanding to solve the problems of this and any other accident in all their depth. The study of normal operations, presented in this third part of the case study, and particularly three characteristics of the EDIA organization which it reveals, may provide deeper elements of understanding about the limitations of the current accident analyses and learning:

-Organizational fragmentation resulting in fragmentation of the safety information system and its management,

-A process of filtering information leading to amplification and treatment of some data collected by EDIA, but blocking of other data,

-Single-loop learning which does not provide an in-depth understanding and solution of the problems identified.

These three characteristics will be shown to prevent EDIA from including weak signals in accident analyses and from passing from organizational single-loop learning to organizational double-loop learning.

4.4.1 Processes of detection, transmission and treatment of safety data

We will first of all describe the system of information processing implemented on the EDIA site, especially relating to technical and safety anomalies. This analysis will shed light on the tools and methods used to detect, transmit and process information during normal functioning.

4.4.1.1 Anomalies: definitions

From our first days at the EDIA site, interviewees made the link between what they said about weak signals and anomalies as defined by the site, considering it to be sufficient to detect and treat anomalies in order to solve the issue of weak signals. The association established in their minds between weak signals and anomalies led us to pursue the latter notion. Several EDIA documents refer to it. The SMS manual states in a paragraph referring to the procedure for "Managing anomalies": "*A second level*[25] *of control is ensured by all visits, audits and inspections conducted on the site (...). They are designed to cover the entire site and are provided by members of senior, middle and first line management level.* "

This section of the SMS defines anomaly as follows: "*Anything that leads or could lead to a loss of any nature affecting personnel, environmental damage and complaints from outside, property damage, fires, explosions, decreased production, achieving benefits for our customers (quantity, time, quality*)".

Finally, the quality manual for plant inspection indicates that an anomaly is: "*Any deviation from the expected state of pressure equipment subject to monitoring*" (p.3).

Anomalies are therefore seen as deviations from expected operation, to be discovered by monitoring of all sorts. We observed a wide variety of types of anomalies listed on the site. This

[25] First level of control is the reporting of critical events.

extensive categorization has the merit of covering a wide range of risks, but at the potential cost of getting lost in the increasing accumulation of data.

We use the following categorization to discuss the anomalies listed by EDIA:

-Technical anomalies

- Damage to equipment: anomalies labeled OA (Operational Anomalies)
- Inspection of facilities under regulatory surveillance

-Safety anomalies:

- Workplace audits and other kind of anomalies observed and reported through a specific database called CAT[26] (Constats d'Anomalies Traitées)
- Quality visits
- Scheduled General Inspections (SGI)

We will start by describing the process of detection and treatment of technical failures including:

-Operational anomalies processing meetings

-Coordination meetings,

-Work authorization meetings.

These processes will allow us to observe the transmission of information from the core operational activity to the decision-making centres.

4.4.1.2 Detection and treatment of technical anomalies: a coordinated operational safety

Maintenance of equipment and facilities is organized according to the following time scale:

-Daily maintenance and emergency repair: treatment as OA,

-Medium term maintenance planned by the maintenance method service: preventive maintenance,

-Long-term maintenance covering major projects and planned outages.

For a number of reasons our study of normal operation led us first to observe meetings where the OA were processed. These meetings are daily, which allowed us to "systematize" our observations and collect sufficient data (in quality and quantity terms). Also, these meetings report and treat operational anomalies (as announced in the introduction) found during normal functioning, and allowed us to observe the criteria (priority, severity) used to treat such OA anomalies.

[26] CAT means "Constat d'Anomalies Traitées" in French (Notice of Anomalies dealt with in English). We will keep the French acronym in the whole chapter.

4.4.1.2.1 Operational anomalies (OA): detection and transmission

Every morning from 8:30 to 9:30 each of the three production units sets up a meeting to report and treat technical anomalies (OA) detected the day before (about 2000 OA per month are processed in total). OA are most often detected by EDIA operators or a subcontractor, but also by inspectors (responsible for monitoring specific installations). They are entered into the SAP database (Systems, Applications, and Products for data processing), by the person who detected the anomaly. This software provides a precise and complete description of the anomaly. The transmitter assigns a label to the OA, indicates the equipment on which the anomaly was identified, the nature of the anomaly and the priority for treatment. There are two types of OA: Level 1 processed by the operational area, and Level 2, transmitted only by inspectors and processed by the inspection service (we shall return later to the OA level 2). Finally, the transmitter of the OA chooses the relevant service which must organize the maintenance work: mechanical, electrical or instrumentation. OA are transmitted to the foreman of the production unit concerned, by email. The latter is responsible for collecting all the OA in his unit to be considered at the daily OA meeting.

4.4.1.2.2 OA treatment: a coordinating process

OA meetings are set up in each production unit. They are composed of the production unit manager, his foreman, a preventionist and a representative of the subcontractors. The production unit manager reviews the OA and gives them a priority, which may be different from that proposed by the transmitter of the anomaly: priority 1 means immediate treatment (that day), priority 2 the day after, priority 3 within the week and priority 4 within the month. If the OA is defined as priority 4, it is subject to a work demand managed by the maintenance method service. OA priority 1, which are essentially technical, are immediately processed with an intervention request.

Coordination meetings are intended to deal with OA for which an intervention request has been made out. This is taken on board immediately by a designated subcontractor. Through the computerized system for delivery of work authorizations, the subcontractor will automatically receive a request to intervene and solve the technical anomaly or anomalies detected. He transmits this work authorization to the production unit where the anomaly was detected. These work authorizations are then discussed during the coordination meeting.

Work permits must be agreed by the production unit manager, but many actors are involved in this process: maintenance and safety staff must also agree and sign work permits so that they can be delivered to the subcontractors. Work permits must include the following elements:

-The names of the subcontractor and the person requesting the work (supervisor),

-The exact nature of the work to be carried out,

-The risks related to carrying out this work, specified by the supervisor and subcontractor,

-The risk control measures (tag, atmospheric condition monitor, etc) specified by the safety staff,

-The personal protective equipment specific to the activity (e.g. earplugs) and personal protective equipment required by the refinery (helmet, glasses, shoes).

This work permit, once accepted, provides a document (Bon de validation) which authorizes contractors to work within the site.

The coordination meetings have two purposes. The first is to deliver the work permits allowing subcontractors to work on the equipment on which the anomaly was detected. The second is to coordinate the coactivity between subcontractors working in the same production area. So this is a crucial time devoted to the safety of the subcontractors' employees and working conditions for the maintenance work.

OA treatment is a good example of information processing and operational Rex:

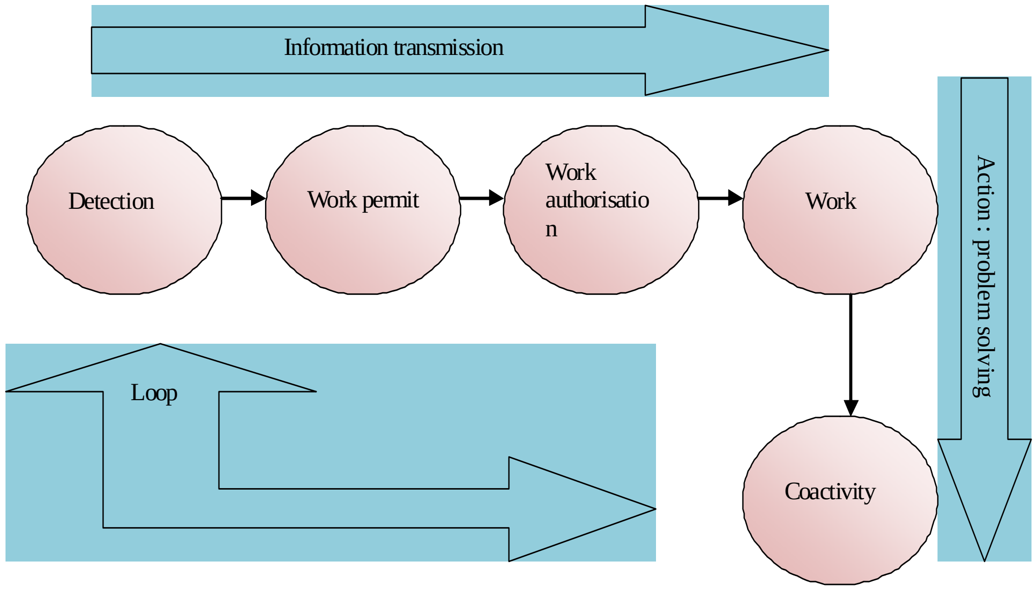

Figure 12: Process of technical anomalies detection, transmission and treatment, EDIA.

This process of communication shows schematically the five major stages of detection, transmission and processing of OA which can be summarized into three main stages (the blue arrows in figure 12):

-The transmission of information: from detection to work permit,

-Action: the intervention,

-Closure of the loop confirming treatment of the anomaly initially detected by and validated in the SAP software.

It reveals instructive features on several levels. It is a homogeneous chain of transmission of technical anomalies. The process of detection and treatment of anomalies is provided by common software, and anomalies are treated using the same procedure by all three production units. It also gives a central place to safety. The latter is ensured by the expertise of the safety coordinators who play their part throughout this process. They study the work authorization requests, add new safety measures if necessary, and, finally, validate the permit to work in the coordination meeting (adding their signature). They are therefore playing a role in the tradeoffs between production requirements - tight scheduling, result-orientation, strong pressure to restart the plant after maintenance work - and safety requirements, but also play a role in checking compliance and verification of the work against safety principles during and after the intervention.

Treatment of technical anomalies is an interesting way to observe how operational safety is organized, built in this case on the requirements for corrective maintenance. They are nonetheless also part of a global preventive and proactive maintenance in the EDIA refinery.

4.4.1.2.3 Major accident prevention: main objective of operational safety

As we have briefly introduced in the general introduction, the EDIA site puts much effort into maintaining the reliability and availability of its plant. This therefore requires not only management of technical anomalies in the short term (or corrective maintenance) but also in medium and long term.

Preventive maintenance is provided by the maintenance methods service (part of the maintenance department). It sets up a schedule (maintenance regime) for monitoring plant to provide preventive or curative maintenance. Depending on the condition of the equipment (through regular monitoring) or the frequency of anomalies reported (through inspections or OA), the system can be stopped for maintenance or continue to work in anticipation of a scheduled stop in the longer term.

Some equipment under mandatory regulatory control is managed by the inspection service. It monitors 1500 pieces of equipment (out of a total of 2000), twenty-nine pipelines exiting the site (out of a total of 75), 1600 valves, six ovens and three boilers. The monitoring of such equipment must be done by a combination of methods:

-Visual monitoring through visits, inspectors' reports on anomalies such as corrosion. Every day, they inspect equipment, and if they observe anomalies, write a report that they send to the head of the inspection service:

Observation of an inspection round:
We climb on to an oven of the « atmospheric distillation section. As inspector has to monitor the columns and inox of the oven in which gas-oil at 400°C circulates. To do that he opens three sight glasses through which he can check the state of the columns and through which he can clearly see the flames impinging against the columns.
I ask him what are the signs of degradation which are observable on the columns and stainless steel: he looks to see if they craze under the effect of the heat, that is to say if the stainless steel shows any cracks, which would lead to a hole in the tube and a leak of gas and heat.
His observations are noted on a form and sent to the inspection service the same day.

-Computerized follow-up of indicators called COCL (Conditions Opérationnelles Critiques Limites – Critical operational limit conditions). These indicators, placed on the plant and monitored by a program run by the inspection service, detect excedance of critical thresholds on the classified installations monitored by inspection:

"For example a furnace must not exceed 600 ° C to prevent ageing too fast. If the temperature rises too much, you are warned at the thresholds (COCL). We set up a correction and we monitor the anomaly "(...) Based on the COCL, we can say ok we can let it go for a while but then it will need to be decommissioned. So we make regular checks to see if the degradation is increasing up to the point it could become an accident" (Inspection)

-Operational follow-up. In coordination with the maintenance department, the inspection may take over treatment of certain technical anomalies (OA) at level 2 (see section 4.4.1.2.1) if they cannot be handled by maintenance. Common software between the services provides the interface between them, automatically exchanges data, and enables a coordinated treatment of technical data.

The EDIA refinery, as a Seveso upper level site, because of the quantities of dangerous materials stored and used, leading to risks such as fires, explosions and toxic gas releases, must implement a policy for the prevention of major accidents, which are defined as follows by the Seveso II Directive (Source: Safety Management System manual, June 2006): "*A major accident means an event (emission, fire or explosion) of major importance, resulting in uncontrolled developments during the operation of a facility covered by this Directive and presents a serious danger to human health, inside or outside the establishment and/or the environment, either immediate or delayed, and which involves one or more hazardous substances.*"

To define the objectives, it is necessary to assess the level of acceptable risk, that may be different according to the country. Major accident prevention follows the following stages:

1. **An assessment of potential hazards and risk analysis of the refinery.** Major accident scenarios (with effects outside the site) are built up through the study of internal (Rex forms) and external databases like BARPI:

> *"For major accidents we base risk analyses on the internal analysis but also the analysis in a working group. This is a HAZOP analysis, looking at deviations and the impacts of these deviations. The result is a list of prevention measures and safety barriers to put in place. We conduct the meeting with production units which bring their experience of the activity which we are not always aware of. We make a calculation to see if this scenario can have off-site consequences. If this is not the case, we make no detailed analysis" (Major accident manager)*

The detailed risk analysis is presented in the form of a “bowtie”, which illustrates, for each potential scenario of a major accident, the direct and indirect causes of the accident sequence, the indicators of deviation to be put in place and monitored, the safety barriers (the most important are called EIPS [Eléments Importants pour la Sécurité[27]]. EIPS are identified by the head of the major accident service but followed-up and modified, if necessary, by the production unit where the barrier will operate, and maintained by the maintenance department (reliability tests, spare part availability for example).

2. **A systematic quantification**. EDIA site makes a distinction between major accidents having an effect outside the site, for which a detailed risk analysis will be completed and major accidents whose impact is confined to the site boundaries, for which a simple risk identification and impact is produced:

> *"So for scenarios that have effects outside the site, we model them by using a matrix dating from September 2005. According to the combination of the severity and probability we determine whether the risk is acceptable or not. Before this there was no calculation methodology. It was semi-quantitative. Nowadays, we apply a quantitative method. This matrix was produced after the AZF disaster and it is a transcript of the 2003 Act”.*
> *“It is a probabilistic method that you use?”*
> *“Yes it has an international basis. Regarding the scenarios, we also measured the range of effects of an accident and the off-site populations that may be affected. That gives us the local severity. So modeling scenarios it is the likelihood and severity that define whether a risk is acceptable or not." (Major accident manager)*

3. **The dynamics of the scenarios identified**. Major accident prevention includes not only risk analysis but also a Prevention Plan for Technological Risks (PPRT [Plan de Prévention pour les Risques Technologiques]):

> *« According to the probability that a major accident scenario can be extended over an area, we draw circles taken from risk analysis, which give, the associated probability and range of lethal effects. These circles are superimposed on those of neighboring plants and measure the levels of hazards and preventive measures to be put in place. These measures may be: reinforcing windows to prevent them from exploding, reinforcing house structures. That can be everything up to expropriation of the property." (Major accident manager)*

[27] Important Elements for Safety.

Major accidents policy is therefore based on the identification and modeling of scenarios, including the deviations identified for the accident sequence, and barriers to control and correct those deviations.

In conclusion, the study of the transmission and treatment of technical anomalies reveals an operational maintenance policy and plan covering several dimensions:

-A severity scale from curative treatment to the prevention of major accidents,

-An organizational plan: a coordinating organization between production units, maintenance, safety and the major accident services,

-The pursuit of a common goal: to ensure plant reliability and prevent major hazards.

We turn now to what is covered by “procedural (or administrative) safety" ensured by the quality department.

4.4.1.3 Safety anomalies: fragmented management

Safety anomalies are managed by the quality department. In contrast to technical anomalies, their treatment is not characterized by coordination but more by fragmentation.

4.4.1.3.1 Workplace audits and Anomaly Reports and Treatment (Constat d’anomalies Traitées: CAT)

Workplace audits are a project born out of an initiative of the EDIA site, and more particularly of the safety service. They are mostly carried out by preventionists (80%), with 20% by maintenance operators. These audits are intended to check the progress of works being completed by subcontractors.

The safety service has six preventionists. Although hierarchically linked to the safety service (which is a central service), they are each responsible for ensuring visits to a specific production unit. Every two months, there is a changeover of the assignment of safety coordinators and they move to another unit. This organization is devised to try and balance two objectives: integrating safety coordinators into the operational units, whilst at the same time maintaining a certain independence of the units by regularly changing the units where they carry out visits.

Preventionists must make one hundred site visits per month. For that, they organize daily audits at "random" and check works maintenance in progress. They use a form containing the following items (appendix 4):

-Correct obtaining of a work permit and completion of work mentioned

-Personal protective equipment

-Specific risk control measures specified in the work permit

-Means and tools used on the site indicated on the work permit

-Compliance with preventive measures (e.g. use of a explosimeter)

-Compliance with general regulations (e.g. smoking prohibited)

> Observation of a workforce audit:
>
> The preventionist audits a work consisting of two people: a worker digging the ground with a mechanical digger and a second, monitoring the operation from the outside. The preventionist stops the work and asks the worker monitoring the digger for his work authorization. Both workers give him their work permits in which the auditor verifies that the collective protective measures related to excavation work (Annex 4 "collective protection") and the associated "excavation permit" as registered and required in that document, are being respected. The site is also fenced off, so everything on the audit is in order. The safety coordinator then asks the two workers whether it is permitted to dig the ground here with the digger. The safety regulations stipulate that, due to the possible presence of underground cables, the subcontractors have to dig manually up to 1.20 m depth. Only below that may they use a digger. The safety coordinator asks them to measure the depth of hole: the site is within the norms. Finally, the operator asks the two workers where the warning sign is indicating that digging operations are under way. The auditor finds it to be poorly located and asks them to make it more visible. They move it. The auditor takes out a safety form for the site visit, fills it in and ticks all items "in order". He gives a copy to each worker and permits them to resume work. We leave.

Non-conformities on any of these items are evaluated according to a severity scale: severity 1 or severity 2. The sum of any anomalies, graded according to their seriousness, gives a final score, which can be handled in one of two ways (appendix 5):

-Level 1 or minor severity: the report is monitored in a database managed by the safety service. Anomalies are classified according to their monthly observed frequency per subcontractor, in the form of histograms.

-Level 2 or greater severity: the audit forms are transformed into a CAT (Constat d'Anomalie Traitée) and are managed by the maintenance department. CAT forms allow the reporting of a wider range of anomalies: technical, safety, environment, purchase. A CAT may be issued in two ways. It can be filled in by anyone from the site to notify an anomaly fitting the category, or by a safety coordinator who has evaluated non-conformities in an audit as severity 2. In this case, it will be a labelled a “safety CAT”.

4.4.1.3.2 Scheduled General Inspections (SGI) and quality audits

In contrast to audits and CATs, which are an initiative of the site, the completion of Scheduled General Inspections and quality audits are required by the ISRS (International System Safety Rating).

SGIs are conducted by shift supervisors once every two months and aim to observe the conditions of workplaces and buildings. Anomalies detected, mainly related to material defaults (appendix 6) are categorized as follows:

-Conditions of workplaces (floors, platforms, exits, etc,)

-Buildings: ventilation, noise, lighting, etc.

-Materials: storage, chemicals, waste management, etc.

-Emergency arrangements: fire extinguishers, eye wash and showers, etc.

SGIs are rated according to a severity scale: A serious, B moderate and C minor. They are not conducted randomly but according to a very specific program. The site is divided into geographic areas to be covered by the auditors. The reports are recorded and processed by the quality service.

Quality audits are conducted by the line management (appendix 7). The works manager and heads of department must conduct a quality visit once or twice per quarter and heads of production units one visit once a month. The reports of quality audits are rated on the same grid as that used for SGIs and recorded by the quality service. For each anomaly detected a remedial action is decided and one person is appointed responsible for the action, whilst the quality service monitors implementation and follow-up. In the same way as for the SGIs, all geographic areas of the site must be covered.

These audits have two objectives. On the one hand, they cover any deficiencies broadly across the entire site and, secondly, as proposed by ISRS, they involve the entire management chain in matters relating to safety (we will return later to the principles and objectives of ISRS as audit and embodiment of the safety management system).

4.4.1.3.3 How are safety anomalies handled?

The treatment of safety anomalies is one of the fundamental issues that we address in Part III of this document. We observed two types of processing parallel:

- Organizational single-loop learning from anomalies provided by the CAT committee,
- Poor quality of learning gained from SGIs and quality audits

****CAT treatment: organizational single loop learning***

CATs committees were interesting to observe. They are dedicated to the review of CATs either reported by staff or from non-conformities of gravity 2 noted during the audits of workplaces (transformed into CATs, see section 4.4.1.3.1 and figure 13).

CATs committees have existed for four years. At their launch, the managers of the maintenance method and quality services brought together the main sub-contractors to give them a set of tools which they could use, if an anomaly was detected, to meet the site and CATs Committee requirements in terms of safety. For the CATs committee's members this is a tool to improve the safety practices of sub-contractors, among others.

The committees meet monthly and are staffed by Maintenance Methods, Quality and Safety:

Example 1: During a site visit, a preventionist observes that a company employee of SANINORT did not have his work permit. This audit non-conformity was assessed as severity 2, and was therefore the subject of a CAT. The action proposed by the subcontractor: setting up a safety toolbox meeting for all his employees to remind them of the basic rules of work required on any construction site of EDIA, including the issue and retention of a work permit.

The preventionist is responsible for sending the CAT request to the subcontractor in question (the transmission is ensured by the safety service). After receiving the CAT request (see figure 13), the sub contractor has to send the analysis and action plan to resolve this anomaly within three weeks. The response is reviewed by the CAT Committee, which meets once a month to review all responses sent by the subcontractors.

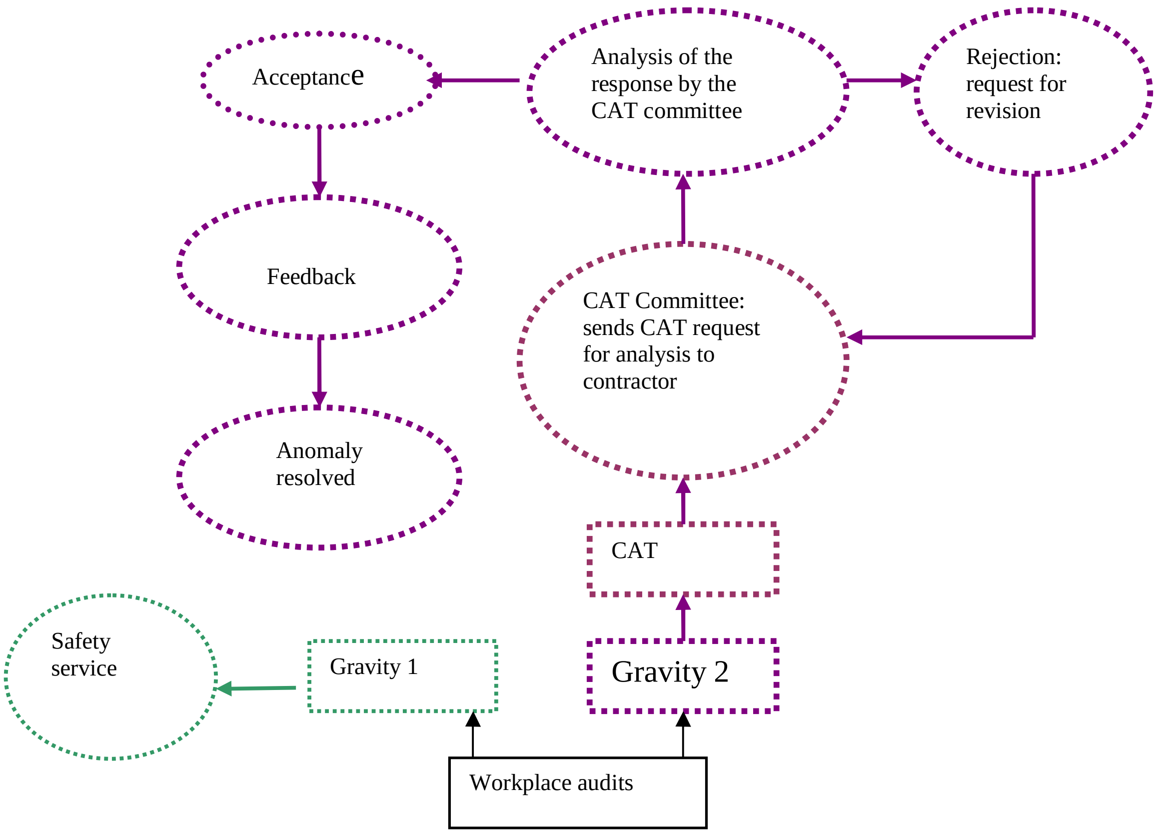

Figure 13: Treatment of CATs, EDIA.

Legend: purple lines: CAT committee (maintenance) ; green lines: audit treatment (safety service).

Example 2: During a site visit, a safety coordinator observes the lack of individual and collective safety measures on a worksite of the subcontractor PAIC (cleaning company). In response to the CAT request, the team leader PAIC held a meeting with his relevant staff, suggested that they follow a refresher of the induction training for the site and also put in place a safety toolbox meeting to highlight the importance of safety goggles (PPE) and fencing off the worksite (collective protection). To evaluate the effectiveness and sign off the dossier, the CAT Committee requested a copy of the toolbox presentation, and a copy of the internal briefing note which they had circulated.

The head of the CAT Committee noted that the company "*goes a long way in its response and is even proactive. There are fewer issues to raise with them. They are, after all, part of a larger group which has a system of quality management. They fired everybody up, which is good, and they can offer something to EDIA and to other suppliers. They should share their experience*."

In these committees, subcontractors' responses are analyzed. The commission checks:

-The relevance of the root cause analysis and proposed actions: toolbox meetings, internal notes, etc,

-The proof of actions taken to show that they have been applied (documents and presentations must be attached to the file).

If the response is accepted and signed off, the CAT committee considers whether the anomaly has been resolved. Otherwise, the committee sends back the response to the subcontractor and requests a review of the analysis or action plan or both. CAT files are registered and managed by the maintenance department.

The importance of the CAT committees is twofold. First, they reserve a specific time to analyze and solve the many anomalies detected. They enable the identification of the occurrences of anomalies and by integrating data, identify patterns of repetitive failures, which are still unresolved and for which further analysis may be necessary. Secondly, in the same way as the OA (operational anomalies), CATs are processed by a team consisting of people from different departments, with different expertise. The committees have led to a sharper observation and handling of anomalies and any repetitions of them.

The members of the CATs committee specifically noted an evolution in the treatment of anomalies and a significant decrease of CATs after the second year of their existence, and improved analysis and actions proposed by subcontractors:

« In 2007 there has been an evolution, CATs are decreasing…"
"And that is due to what?"
"To the action plans which have been put in place… And then certain measures have been put in place. In respect of people who smoke sanctions can be taken, which means they do not smoke any longer. There are a few recidivists, but not regularly. Safety is often about banal things, without immediate consequences… But

there is a greater awareness of dangers. I know we will never reach target 0 … but CATs don't only relate to safety anomalies, they are also about quality, delays, etc. .. such things will always happen"
"And CATs have been in place for 18 months, is that right ?"
"That is longer than that ; the first was in 2005. That was the start. We improve the tool from year to year. In 2005 we didn't have so many, but in 2006 we had the peak : 216, which, if you divide by 12 is 15 a month, without counting the anomalies which were not counted in CATs"
"And what criteria were used to decide that?"
"For that you have to see with a preventionist. But I know that before we dealt with anomalies which are no longer CATs"
"Is that why they have been dropping?"
"Yes, but it is not only that, there is also more awareness and care. In addition it gives the sub-contractors a good press if they have a lot of CATs and it's in their interest to reduce the number of CATs" (CATs coordinator).

However, we raise the following question. When several items checked through the audit are rated severity 2, the audit non-conformity is transformed into a CAT. We can ask why specific items are considered more serious. On what criteria was the severity scale built? This is not explicit.

When we look at the analysis and actions proposed by subcontractors, as required by CAT Committee, they are often limited to the technical dimension of the anomaly identified, and to a reminder of the rules and procedures and the need for compliance. Acceptance of these responses as sufficient by the CATs committee seems to reduce its actions (and its value) to simple compliance with its procedures (and proof that actions were put in place). Therefore, we may conclude that the treatment of anomalies ensured by the CAT committees is limited to organizational single loop learning here and there: CATs Committees do not seem to question the relevance and effectiveness of their own procedures, and actions proposed by the subcontractors are often limited to a reminder of the correct application of rules and monitoring procedures at an operational level. There is no evidence that this learning helps to understand the root causes of these anomalies. We can question also whether the depth of analysis required of the subcontractors is enough to solve the occurrence and repetition of anomalies.

SGIs and quality audits: failures of learning?

Each of the SGIs and quality audits conducted is completed and recorded in a database managed by the quality service. Despite the use of a form setting out a procedure for detection and treatment, these audit tools seem to suffer from a lack of analysis, which is deplored by some personnel:

"So, how can we work together [across departments] when we have difficulty to work together even within the same department?"
"Are you the only one to feel that, or is that shared with others?"
"No we all feel that a bit. There is no sharing of the basic principles, so tools just accumulate and how should we rediscover them?.... Here the problem is to see what the link is between the tools. I believe we should think deeply about an organization for doing that." (Quality service manager)

"We conduct audits, inspection rounds to discover anomalies, but we don't do anything with them." (Quality service employee)

"Up to now anomalies are detected through all sorts of (indirect) tools, but not analyzed in the same database. There are lots of tools and we get lost in them." (Quality service manager)

Within these two tools, the quality service should have the necessary, but not sufficient, components to initiate a process of data analysis of these SGIs and quality audits. The lack of methodology and of coordination with other departments or services (which does happen in the case of OA processing) are, according to us, a major obstacle in making sense of these data. Both tools seem to fail in their purpose of treatment and learning because the lessons learned from them remain poor. Table 2 summarizes the process of detecting and treating safety anomalies.

Detection				**Treatment**	
Steps / **Anomalies**	Detector	Categorization	Responsibility	Treatment	Management & learning
Workplace audits	Preventionists and maintenance fitters	Form (annex 3)	Safety	Gravity 1, database safety Gravity 2 CAT (annex 4)	Gravity 1 ; Safety. Single loop learning CAT: Maintenance Single loop learning
Quality audits	Quality and line management	Form (annex 6)	Quality& production units	Matrix of gravity A, B or C	Quality Poor learning
SGIs	First line supervision	Form (annex 5)	Quality & production units	Matrix of gravity A, B or C	Quality Poor learning

Tableau 2: Detection and treatment of safety anomalies, EDIA.

To summarize, we observed two types of processing of safety anomalies. The treatment of CATs and workplace audits of severity 1, provided by maintenance department, leads to single loop learning. SGI and quality audits, carried out respectively by foremen and heads of departments, appear to lead to poor learning. Whilst workplace audits and CATs which are inventions promoted by the EDIA refinery, have an operational anchor, which gives meaning to these data (because they refer to the technical and procedural dimension which is very predominant in the EDIA refinery), safety anomalies reporting via the SGI and quality audits, managed by the quality department, which is a centralized and procedural service, do not seem to make sense for the safety auditors from the operational area, but also not for the quality department itself. SGIs and quality audits seem to consist of little more than a process of data storage, rather than data treatment.

4.4.1.3.4 Critical events

****Detection***

Since 2003, the refinery has used a tool for recording critical events[28] called EVEN +. Everyone on the site may notify a critical event and record it in this database. Training in the use of the tool is provided to every new EDIA employee. It consists of the following elements:

After detection or observation of a critical event, an "incident report" is filled in. The detector of the event is not in all cases the person completing the report. Indeed, it is stated in the procedure for using the tool EVEN +: "*Every person can create a report and particularly the first level supervision (shift supervisor, foreman) that plays the role of 'motor' in achieving their registration and analysis* "(Manual of Safety Management System, p. 22). In other words, although the event can be seen or detected by an operator, the line management is responsible for reporting and analysis (this item will be tackled in more details in section III of this chapter).

The event report includes (Source: Manual of the Safety Management System).

-**The category of the event**. EDIA site make a distinction between "accidents" defined as unforeseen events generating occupational injury, and incidents (unforeseen events generating process damage), and near misses. The latter means that, in other circumstances, the event could have been more serious and is considered as an accident or an incident. The manager is responsible for the way in which the event is labeled, and for the completion and sending of the report to the EVEN+ database.

-**Evaluation of the risk** based on the seriousness and frequency. Events are rated according to a severity scale: A "major severity" (the severity of the accident that we have analyzed in Section I of this chapter), B "moderately serious" or C "minor severity". In-depth analysis depends on the severity assigned by report sender. For each severity A event, EDIA applies a specific procedure requiring: the dissemination of information internally and externally (to other EDIA refineries), a root cause analysis, a reconstruction of the accident and information to the company safety committee. Events graded B and C require an analysis provided by an investigation report and are not shared with other EDIA refineries.

[28] According to the EDIA site classification, critical events are events which are neither anomalies nor major accidents. They are significant but remain limited inside the site. Lessons learnt after critical events are not shared with other EDIA refineries.

-**Facts and potential consequences**. Event report forms provide sufficient space for a description of the circumstances of the event (free text), as well as a categorization of consequences which include: damage to property, damage to the environment, production losses, fires, quality events and environmental complaints (complaints from the surrounding population about noise, odour).

-**Analysis of causes**: the tool allows a distinction between two types of causes: immediate causes are non-standard actions or conditions and the root causes are human factors and work-related factors. In other words, the EVEN + tool is used to determine the triggering event, the immediate causes and deeper causes. However, the root causes listed in the software make it difficult for the site to identify the recurring logic underlying the occurrence of critical events:

Interview with the manager of the quality service:
To explain the difference between non-standard conditions and actions he took the following example :
« Someone fell into a hole near the laboratory. It was getting dark. As a result of the analysis someone put that this was a non-standard action, which would have meant that he threw himself voluntarily in the hole. However it appeared that the hole was not fenced off, so it was a non-standard condition. It is too easy to say that it is the fault of the operator ». (Quality service manager)

-**Corrective and/or preventive actions** put in place with a deadline and a responsible person. Depending on the circumstances and the analysis of events, actions and persons responsible for them are proposed by the report sender. These actions can be preventive or curative.

-The identification of **actual costs**

-The **repeatability** of the event

Reports are saved in a database managed by the Quality sector, listing all critical events reported. That service, and the person responsible for the action, automatically receives an email informing them of the event and the drafting of the investigation report. The monitoring of actions and deadlines is provided by the manager of the sector Quality.

The information about in-house critical events is transmitted by the following circuit (figure 14). This communication scheme indicates that the strict categorization scheme ensures that critical events are detected and transmitted largely only if they fall within the given categories of analysis. We show in Section III, how the filters involved in this communication chain block or amplify information transmission.

Critical events processing

Processing of critical events means more specifically exploitation of the data recorded in the database EVEN +. With this database, EDIA produces the following indicators:

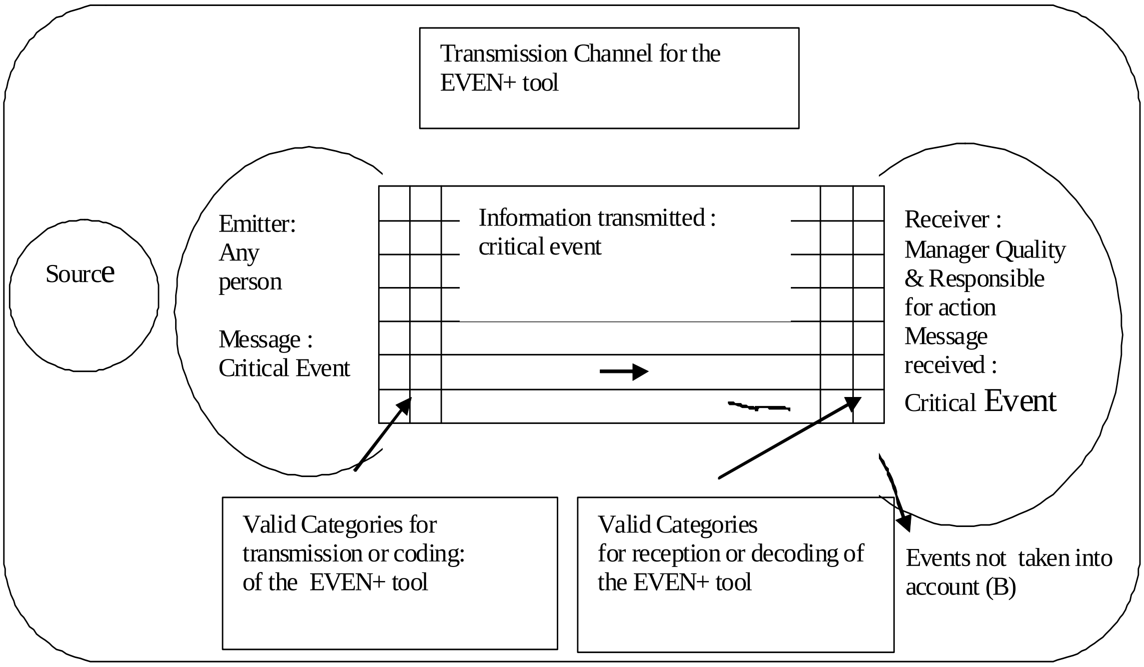

Figure 14: Communication scheme applied to critical events treatment, EDIA site.

1. The trends in the LTIR (Lost Time Injury Rate) that assesses the number of injury accidents with work stoppage per number of hours worked and the TRIR (Total Recordable Incident Rate) which indicates the number of accidents both with and without work stoppage per number of hours worked). Both rates are calculated and distributed by the safety service and allow the site to follow the general trend of occupational accidents of subcontractors and EDIA personnel. However, we note that this analysis is limited to the production of indicators and there are no qualitative investigations.

2. Quarterly statistics of accidents: by type of accident (with or without work stoppage), body part affected by the accident, the age of the injured person, activity and time of day of the accident. These analyses are carried out by the quality service and are limited to a numerical representation as a percentage of the items outlined above.

3. Statistics of events according to nature and consequences

4. Finally, analysis of the causes of events for each type of event and nature of the consequences. This causal analysis is limited to a cross-tabulation between the causes which can be extracted from the EVEN + database and the most commonly recurring types of event:

Informal interview with an employee of the Quality service, extract from the log book:
This employee observed that a large number of reported events had not been analyzed (the immediate and root causes were not recorded). In 2007 of the 248 reported events 102 had not been analyzed in this way. Of the 102 three accidents were in severity category A. In the EVEN+ tool there is a tab « absence of cause » which allows you to extract all events for which no cause has been attributed. I asked him why he had undertaken this action; he replied that for some time he had felt that there was a drop in the analysis of events. He had alerted his management superior (the head of the quality service), who had reminded the people who had filled in the reports of the events concerned, but this reminder had been in vain.

These analyses are, from our point of view, quite limited insofar as they offer in most cases only statistical representations of recurring events. From our observations, the EDIA site does not have a method to analyze the nature and relevance of links between (deeper lying organizational) causes and critical events recorded in the EVEN + database. The situation is exacerbated by a lack of causal data filled in in the database, as revealed in an informal interview which took place in the quality service responsible for managing the EVEN + database.

This lack of data on event causes can be interpreted in several ways. The categories of cause given in the tool may not be understood by those reporting, or are seen as not applicable, or those reporting may not understand the importance of causal data for the analysis (which could explain the lack of response despite the reminder from the quality service), or it may stem from the lack of method for global analysis (mentioned above) to make sense of the relevance and links between the causes identified and critical events. The interview with the quality service employee indicates that there is no causal analysis of the accidents. He suggested that there needed to be a working party set up to do this, with full engagement of the top management.

In contrast to data on operational safety, these data related to procedural safety, and specifically here related to critical events, are managed and centralized in one service (quality), whose main tasks are to check compliance with procedures and standards. This double characteristic (centralized department with procedural approach and compliance orientation), coupled with an absence of a formal relationship with other departments to analyze the data, we believe weakens the possibilities to make sense of them. These data are not amplified (and thus not treated) because they are not illuminated by being subjected to analysis through a coordinated range of expertise from different departments. They are blocked from use and reduced to an indicator of compliance with procedures rather than being used for the potential information content in their message.

We have presented the EVEN+ tool in both its quality as a conveyor of information and in its treatment of significant events. It is a large database but contains two limitations: its priority given to dealing with events which are considered as serious and the lack of a method to analyze significantly (that is to say, both qualitatively and quantitative) the underlying factors that led to the events detected. To that extent, we believe that the way in which the transmission and processing of critical events is undertaken filters out some of the data which would enable the development of a deeper understanding of the organizational factors behind critical events.

In conclusion, two types of safety were presented: safety managed by the line, ranging from technical deficiencies to the prevention of major accidents, and safety managed by staff departments, covering safety anomalies and critical events. For each type of event, two channels of communication were highlighted: the transmission of data, which includes detection, transmission and reception of a message, and its treatment covering the method of amplification (or blocking) of the data for analysis and the data on resolution of the problems.

In the following section, three organizational characteristics of the refinery will be described. The concepts of organizational fragmentation, the filtering of information and organizational single loop learning will allow us to understand the difficulties encountered by the site to exploit the data transmitted and processed through the tools we have presented.

4.4.2 Fragmentation and information filtering

The results of our investigations at the EDIA refinery led us to raise the following question: do accident analyses, conducted after the accident, reflect the overall learning system developed on the site and what is the quality of this learning system? To answer this question, we have undertaken, through the study of the normal operation of the site, to expand our observations and analysis, in order to identify organizational factors behind the potential limitations of the EDIA's learning system.

4.4.2.1 Organizational complexity

The study of normal operation allowed us to identify first that the organizational structure of the EDIA site seems to be characterized by complexity. This involves both fragmentation into departments and sectors, and a reinforcement of the independent and uncoordinated competence of these departments. We start from general observations about the overall structure of the site, but home in on a more precise analysis of the safety management of the whole EDIA site.

4.4.2.1.1. Compartmentalization and the building of independent competences

The literature review defined organizational complexity according to two major characteristics (see section 2.2.1): the technical complexity - related to the site's specific business activity - and the organizational complexity of the site. Pierlot & al. (2006) state that the complexity of an organization is rooted in its technical complexity, which leads to the emergence of compartmentalization and a multiplication of stakeholders making inter (and intra) organizational coordination problematic. Thus, a complex organization results in two phenomena. Communication within the organization may fail when transmission of important elements for each person's work is not realized or is incomplete, whilst informal communication does not always solve such failures of formal communication. Coordination can in turn be failing because of a bureaucratic organization, characterized by fragmentation and isolation of certain departments or work groups. In this respect, the EDIA site can be split into two dimensions (Figure 15):

-A longitudinal, integrated organization at the level of production, in the line management. Each sector of production (P) is interdependent, which strengthens the coordination of the three sectors.

-A vertical organization of "silos" of staff departments leading to a relative centralization and autonomy of these departments.

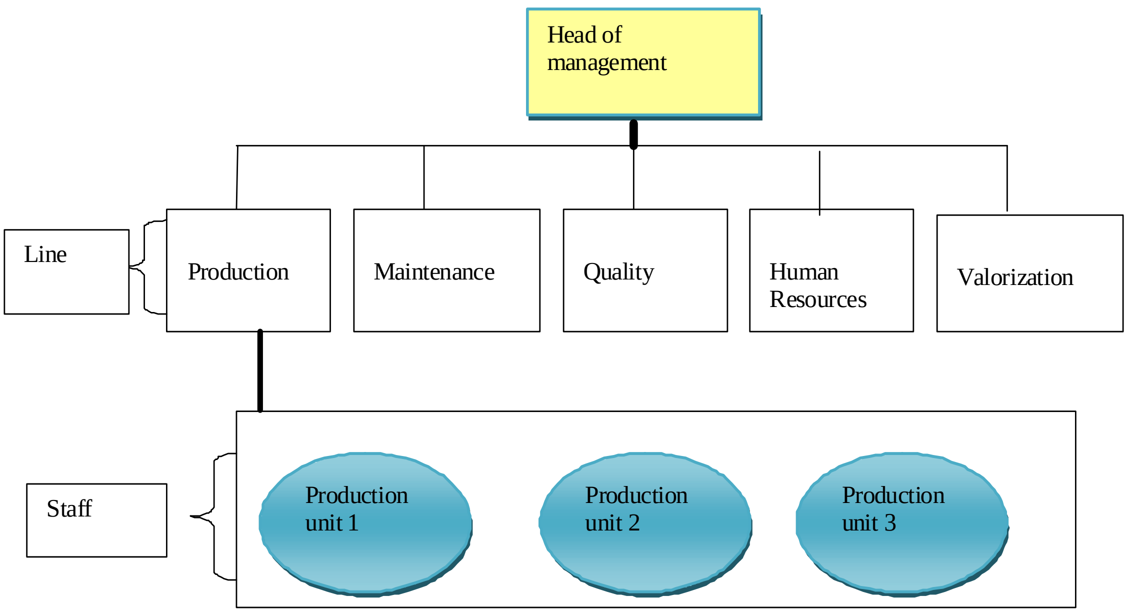

Figure 15: Organizational complexity and fragmentation of the EDIA site.

This organization generates, according to us, two phenomena. First, a distinction (even a gap) is observed between the production line, characterized by integrated and coordinated functioning, and the management level (staff area). Within the staff area, we observed an extensive autonomy and compartmentalization of the departments, leading, in some cases, to failures in communication and coordination. On the other hand, we noted a procedural management of maintenance, and particularly of subcontractors work organization. The work of the subcontractors seems to be split into specific activities, which segments their interventions into separate contracting companies, whereas they intervene in production areas strongly characterized by a continuum and interdependence in their sequence of activities. The maintenance tasks to be carried out by each contractor are rationalized according to the segmentation of activities listed by EDIA, rather than by any analysis of this interdependence. This can, in practice, result in adverse effects on safety (as was described in section 4.3.3.1.1). Here we will discuss the impact of this fragmentation on the management of data related to safety.

4.4.2.1.2 Production units and safety: what coordination?

At the heart of this complex organization, we have identified a distinction between line and staff areas. This separation leads to a distinction between safety managed by the line and that managed by staff departments. The first is characterized by the operational management of technical anomalies which is decentralized and coordinates the relevant expertise of the departments concerned (maintenance, inspection and environment) and answers to an operational requirement, that is to say, to maintain the plant at a satisfactory level of reliability and availability. The second manages data from SGIs and quality audits, which seem to be managed independently of technical anomalies, and are centralized in the quality service. Part of the Safety Management System, the ISRS[29] audit system, requires that a number of tools be implemented by the refinery to ensure loss control, and, according to the design of that system, to obtain the best results in terms of safety. The SGI and quality audits, required by ISRS, have been implemented by EDIA which wished, by fulfilling this requirement, to obtain a higher score on the ISRS audit than that allocated in 2006 (when the site received a score of 8 of 10). However, despite the fact that data collected from these tools are stored in a database as required, the quality service, responsible for managing them, seems to do little with these data to gain value from them. We conclude that data from these two tools (at least at present) serves less to inform the site about emerging risks in the production sectors than to meet the requirements of a safety audit system driven by a party (the Quality Service and the external DNV auditor) external to the operational production units. This second type of safety is characterized by a centralized management of safety data, which is therefore not coordinated with or supported by the other (production and maintenance) departments, leading to a lack of formal relationships and integration between these data and the data about operational safety (management of the technical anomalies).

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[29] ISRS7 is a world-class system to measure, improve and demonstrate health/safety, environmental and operational performance. ISRS7 helps you manage your risks. It strengthens and improves the health of your business processes, provides management tools for advanced decision support and builds the reputation of your business. It also directs your business results and helps you build a competitive advantage (source: official site DNV, Det Norske Veritas).

4.4.2.1.3 Safety Management System fragmentation

Within this issue of fragmentation, we noted another fragmentation affecting EDIA's capacity to treat weak signals. EDIA accident prevention policy is based on the model of the Bird Pyramid, which is an integral part of the ISRS safety audit and management system: figure 16.

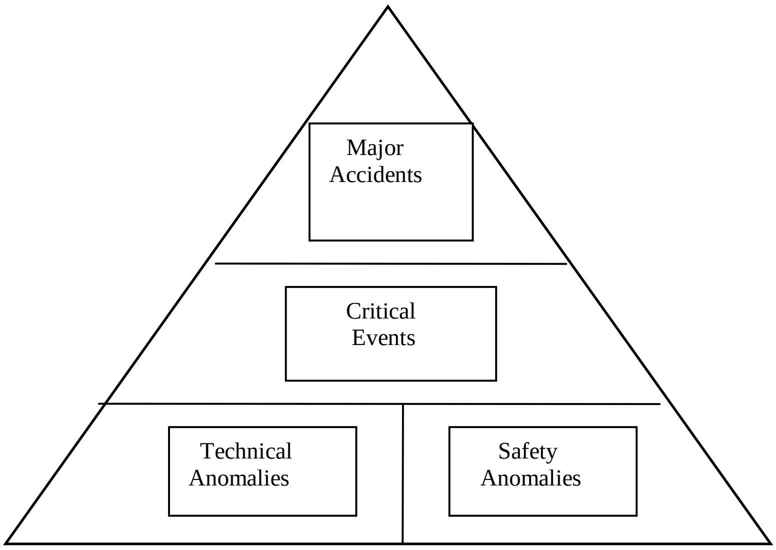

Figure 16: EDIA Safety Management System based by the model of Bird

According to this model, the more anomalies are identified, the more critical events could be predicted and prevented and above this, the more major accidents could be prevented. This implies common causes of accidents exist across the three levels which follow a logical, linear relationship and that data from the three levels identified should be pooled and treated jointly, so that anomalies detected can anticipate and prevent major accidents.

However, we have shown that the site does not do this, despite believing in this relationship. The complexity of the activity on the site creates an organizational complexity characterized by fragmentation at several levels, notably a distinction between the line and staff departments. This leads to a lack of coordination between the disparate sources of data which represent the different levels in figure 16, leading to a loss of information transmitting a message of threat on safety, and the existence of weak signals which could predict an accident if they were listened to.

Should we be so fatalistic? Does the organizational complexity that we have described have to cancel any opportunities for EDIA to develop a method of risk control and thus effectively prevent accidents? We will return to this in this chapter 6.

At this point we need to add one further proviso. There is a flaw in the Bird model, which has been pointed out by Hale (2001). As it is presented in figure 16 and interpreted in the EDIA philosophy, all anomalies and critical events are thought of as having a lesson for preventing major accidents. Hale (2001) points out that this is only true when the minor events are to be found in the same scenarios as the major accidents and can be seen as precursors of them. Many anomalies or minor injuries have no lesson for major accident prevention because they could not credibly develop more major consequences. Hence they merely confuse the picture when we try to discern patterns in the data. It is necessary to filter the data during analysis to allow the real precursors of major events to emerge as patterns.

4.4.2.2 The process of information filtering

The study of normal operations revealed, within this organizational fragmentation, a process of information filtering. Through a detailed study of the communication chain, consisting of the phases of detection, transmission and processing of data related to safety (see sections 4.4.1.2 and 4.4.1.3), we have observed the existence of filters. They are to be found in the transmission chain of the safety data about three levels of severity of incidents: anomalies, critical events and major incidents

4.4.2.2.1 What effects do filters have on communication chain?

A generic scheme for the communication of information is presented in the following section, followed by a sample application to the transmission of technical anomalies, in order to show how filters are involved in the chain of communication of information.

***Generic model**

Figure 17 is modelled on Turner & Pidgeon's work (see Figure 7, section 2.4.4.1.2) to which we have added five filters (red squares, figure 17). These filters operate at several points in the communication chain: information detection, interpretation, transmission, interpretation and treatment.

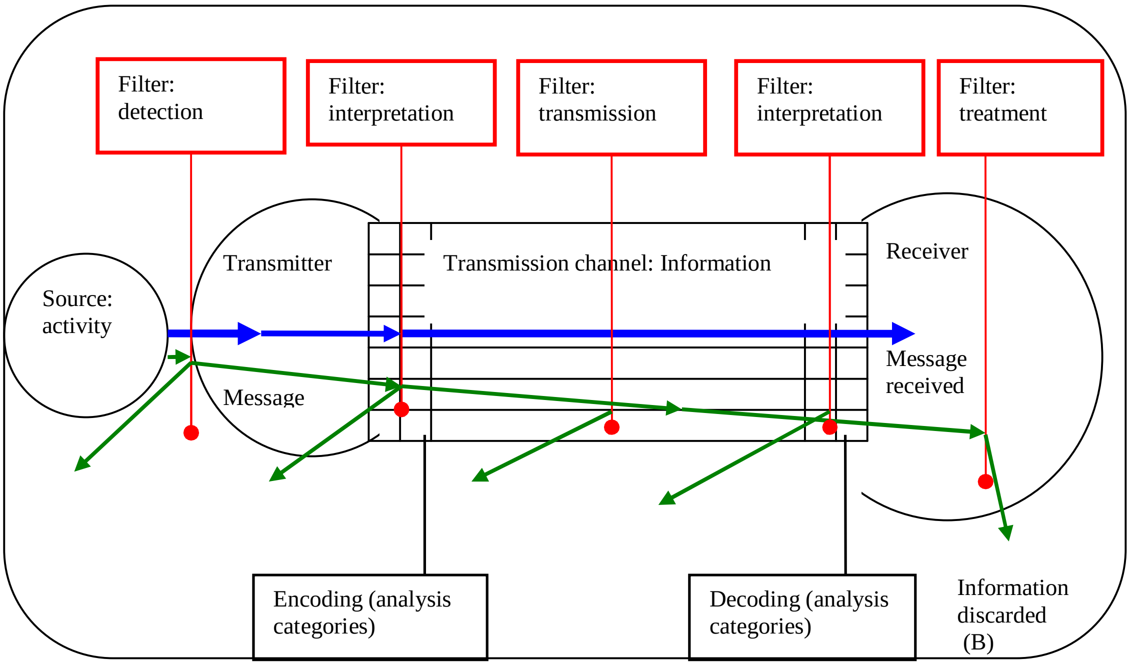

Figure 17: Generic communication chain, inspired by closed communication chain of Turner & Pidgeon (1997), EDIA.

Legend: Blue arrow: transmitted information, green arrows: non transmitted information.

These filters can be of two kinds: they can be tools (such as an audit for anomaly detection, software for data transmission) or organizational. The latter may be divided into several organizational levels: individual actions, collective actions or organizational actions. They may finally lead to two results: amplifying information so that it more easily passes through the communication channel (blue arrow), or blocking information (green arrows), which gets discarded. According to the phase of the communication chain (transmitting or processing), and the type of event considered (anomalies, critical events or major incidents), the filters will have a different nature and action. We argue that the notion of filters, applied to all three types of event listed above, in the chain of communication, is relevant to understanding the problem of weak signals.

***Applied model**

Figure 18 shows the generic model annotated for the transmission of information about technical anomalies.

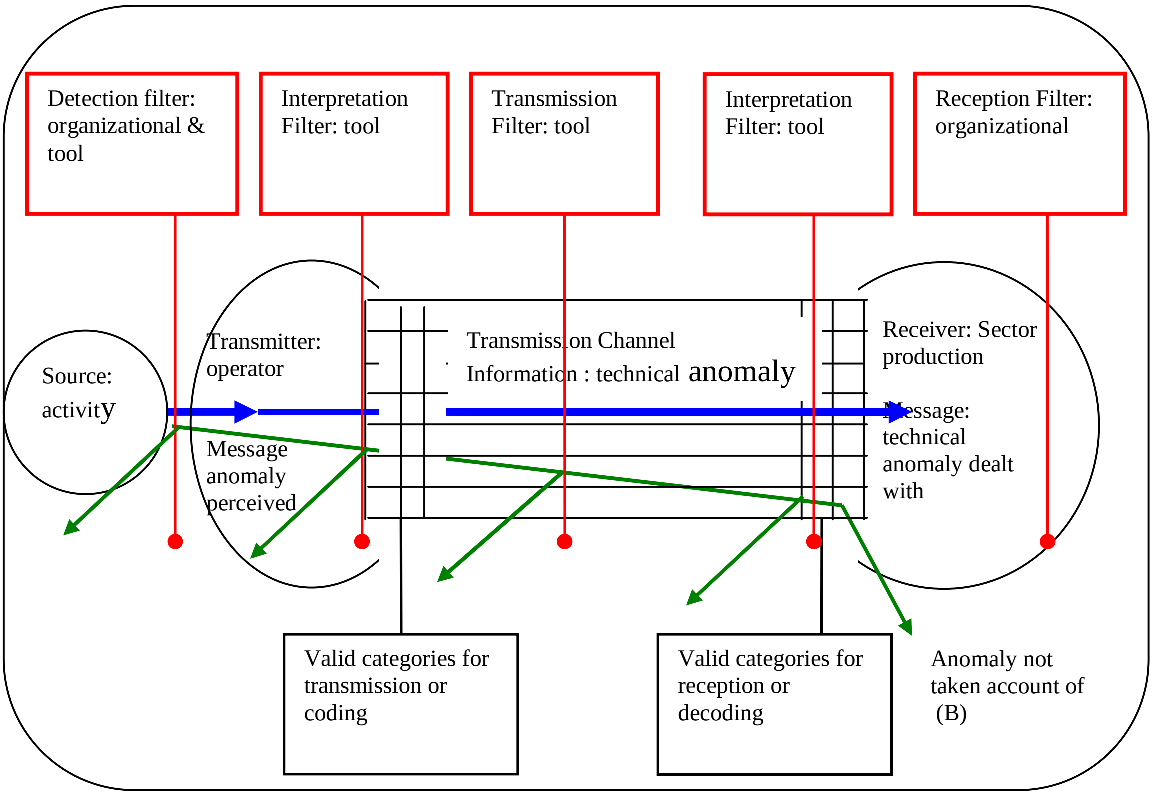

Figure 18: Communication chain, inspired by closed communication chain of Turner & Pidgeon (1997), applied to technical anomalies processing, EDIA.

At the time of the detection of technical anomalies, the organizational filter "individual action" operates. The operator, whose task it is to detect an anomaly may either enhance/amplify the detection (represented by the blue arrow) through his expertise (training, or professionalism) or capabilities developed for the observation of operational surprises, or may instead block the detection of an anomaly (green arrow). Expertise is a double-edged sword, which may, in some cases, generate habits which could diminish vigilance aimed at technical malfunctions. Detection is sometimes done by observation alone, but sometimes it is made possible by the use of a tool, such as a monitoring device that could act as a filter, since it is only designed to detect specific anomalies and not all. In that case it can amplify the observation of an anomaly which it is designed to record (e.g. the SAP software which is used for both recording and transmission of some technical anomalies). However, if the anomaly is not suitable for detection by the tool, then it risks being disregarded.

The second filter acts upon the interpretation of anomalies. The latter are interpreted by using an encoding matrix which defines the surprise or fault (source, nature) and prioritizes the treatment process (as we described in section 4.4.1.2.1). Anomalies not fitting the matrix may be discarded unless there is a category “other” which people are heavily encouraged to use.

This second filter also allocates technical anomalies their priority treatment which governs the transmission of information through the third filter “transmission”, strengthening the signals of high priority and weakening those of low priority. This places a premium on the design of the filter so that these priorities are indeed correct.

The fourth filter "interpretation" works by the same logic. If the anomaly detected and transmitted does not fall within the categories of analysis (or decoding), it cannot easily be interpreted and received in the processing step that occurs in the next phase. The anomaly has been detected but not taken into account in the processing system. Anomalies detected, and having passed through transmission and interpretation filters, will be received by the receiver. The fifth filter "treatment” operates through the process of coordination (OA meetings and coordination meetings for example) between departments which distributes the treatment of technical anomalies according to competence of the different departments and the treatment priorities or time scales (see section 4.4.1.2). This filter does, in this case, allow for the amplification and processing of the technical anomalies detected.

An open communication scheme

Figure 18 shows a closed communication system, which seems to characterize the formal system of transmission and processing of data related to safety on the EDIA site. The consequences in terms of the ability to take account of weak signals are obviously important: the more the system filters and blocks data that fall outside the categories of analysis, the lower will be the chance of detecting "surprises". Surprises, which challenge a closed-communication chain, are relevant to us because they characterize, in part, weak signals.

In contrast to this, we have suggested the need for an open communication chain (section 2.4.4.1.2). We believe it would, in principle, help to overcome the main limitations of the closed communication chain, characterized by its rigidity, by opening or making more flexible every step of the chain of communication. The main contribution of an open communication scheme is that it contains an extra loop designed to question and revise in a dynamic way the analysis categories for encoding and decoding. These are constantly reviewed and adjusted to take into account information potentially ignored, that is to say anything that cannot be interpreted through the analysis categories in force. This revision would open the categories of analysis by adding one(s) specifically designed to capture “other (unexpected) events” and allow the processing of surprises and other dissonant information. An open communication chain does not mean a total rejection of the formal system. Indeed, despite the criticisms we have outlined above, some characteristics indicate that formalization is valuable, if not necessary to amplify the processing of information (e.g. this is the case for the organizational filter "treatment” in figure 18). It is important to recognize not only the value contributed by formal channels for detection, interpretation, transmission and reception of information but also their limitations.

An open communication chain may allow more proactive information processing because it would incorporate not only known information for which a set of knowledge has been built a priori but also unexpected or less known information where there is a need to collect additional information in order to understand the anomalies or surprises in such a way that they can be "tamed" and may eventually be added to the categorization. In this way an open mode of communication, with more flexible categories of analysis used throughout the phases of detection, interpretation, transmission and reception, may allow unexpected events (or surprises) to be processed and not languish as weak signals. This revision of the mode of communication is an active process which requires capabilities to observe new types of information but also innovation in how to communicate them.

Moving from a closed communication chain to an open communication chain would maintain the formal channels for communication of information (SAP tool, severity scale to assess priority of treatment, etc.) but would need to take into account a mode of communication by informal channels.

In conclusion, we have identified filters in the communication chain which, according to the stage at which they occur, amplify or block the information transmission. It seems that patterns of communication at EDIA are closed, that is to say that only data falling into the analysis categories which have been defined as valid for encoding and decoding, are easily amplified and transmitted. To overcome this difficulty, we have proposed the opening of the communication model allowing the site to acknowledge the strengths and limitations of the closed system, particularly in the integration of information such as weak signals, thus adding an important degree of anticipation of unexpected signals, so as to recognize and amplify the message they transmit.

4.4.2.3 Single loop learning: the result of the filtering mechanism and organizational complexity

As last issue in this section, which we identified through the analysis of the incidents analyzes and the normal operation of the learning system, we turn to the limitation of the depth of organizational learning at EDIA.

The accident analysis carried out by the EDIA Refinery and headquarters (Rex team) identified two root causes: a technical issue and a human error. We have shown in the literature review (see section 2.2.2.1) that event analyses are often limited to such technical and human explanations, limiting both the understanding of the accident sequence, the lessons learned from the event and the scope of actions to solve the problems identified. In contrast, the model proposed by

Grabowski (2009) emphasizes the multiplicity of factors leading to an accident. As Reason (1990) has suggested, an accident is not caused by a rule violation (intended human action) or lack of vigilance alone, but is the result of a combination of organizational factors that open the field to informal practices (maybe threatening safety), such as persistence of ambiguous rules, and the necessity for operators to adjust their professional practices to a context of work or production pressure. In this perspective, we conclude that the event analyses and Rex conducted by the EDIA site may be limited and would not identify these types of failure (according to Reason, see figure 2, section 2.2.2.3). In that respect the accident analysis and Rex conducted by EDIA seems to generate at best organizational single loop learning (Koornneef, 2000), since organizational double loop learning requires that the organizational resources, objectives and criteria for carrying out tasks should be modified.

The actions recommended after this case study accident, specifically to reactivate the working group on equipment isolation and lock-off, were an opportunity to continue on the basis of a study conducted a few years ago. At that time, a fatal accident, partly due to a problem of equipment isolation and lock-off, led EDIA refinery to reinforce those procedures in relation to electrical installations. But, after that time, the working group stopped its activities without considering wider issues of isolation and lock-off. After the accident we analyzed, there was good reason to reactivate it. Despite the positive change after the first accident the results of that first working group were obviously not sufficiently broadened to prevent this second accident. The reactivation of the working group and its recommendations after this second accident is a positive sign, but it seems to be only a tentative step towards organizational double loop learning, which has somewhat unclear links to the Rex addressing the accident itself.

4.4.3 Conclusion

In conclusion, we have identified three factors hindering the EDIA site in paying attention to weak signals as it should. Organizational fragmentation at EDIA, characterized by deficient coordination between departments and independent silos, seems to prevent integration and treatment of different data related to safety (operational and procedural). In addition, filtering and amplification mechanisms determine the capacity either to take into account data detected and transmitted through communication chain, if they fit the system’s classifications, or to discard or ignore information of a different nature which would not fit into the categories of analysis. Finally, we observed a method of event analysis and Rex which is limited to technical and behavioural factors of an accident. In this perspective, information about underlying threats, particularly organizational signals, stay or become weak - ambiguous information, spread over different departments, transmitting a message about the threat to safety that remains unclear, because it still falls outside the prevailing categories of analysis. Yet, as we showed in the literature review chapter and through the analysis of accidents, weak signals offer valuable information on two levels: not only could they reveal direct safety failures but also failures of the organization, namely safety management system.

The main weakness of EDIA's safety management system seems to be the lack of a global and homogeneous approach to risk control. As Hale (2006) points out, safety management is the integration of all activities conducted in a coordinated manner by an organization in order to control risks inherent to its business. A department in charge of safety management should not, in this perspective, remain peripheral, but must be well integrated with the operational activities of the organization. We hypothesize that the method of risk control proposed by Hale would provide the EDIA refinery with a global, integrated safety management and effective coordination of safety data transmitted and detected within the communication channels.

I do have to admit that the results found are limited to the scope of the observations made, which were largely focused at the operational level. Collecting more data at a higher management level might have revealed additional data showing more integrated treatment of signals. The EDIA site, for example, has daily DOP meetings (Direction des Opérations de Production = Production Operations Meetings) bringing together production units and safety staff at a higher level than the daily meetings meant to treat OA. I did not attend to these meetings because nobody I interviewed mentioned them as a relevant channel to grasp and observe the issue of weak signals, and I therefore believed, maybe wrongly, that it would not be worthwhile to attend them. At a management level, The EDIA site also conducted weekly management meetings which I did attend each week. These meetings were not so much used to analyze, process and integrate disparate data, but rather for the site manager to transmit information on EDIA Group and its business and, for each department head to present actions, results and plans to be carried out. In no case did I observe these meetings as opportunities to integrate data emerging from the operational level and give sense to them to put actions in place. On the contrary, people in the field agreed on the fact that I should observe signals at an operational level "*the base of the Pyramid* (Bird Pyramid)" as I often heard.

We turn now to the action stage, the feedback sessions.

4.5 Feedback sessions: from a defensive posture to acceptance of the diagnosis

The last part of this chapter is devoted to the presentation of the two feedback sessions that we carried out at EDIA. We will show how they have provided additional elements of analysis to the case-studies, but also to the feedback process itself.

Feedback sessions are part of action-research. It is for the researcher a time of validation and discussion of results. Two feedback sessions were held: the first one to the EDIA refinery and the second one to the headquarters EDIA Group.

This section presents the design and conduct of, and the lessons we have learned from, these sessions.

4.5.1 First session: inadequate design?

The design of the first session was briefly presented in section 3.3.2.1. The following describes more precisely how it was conceived and how it went.

4.5.1.1 Reluctance

The preliminary results of the case study from the accident analysis carried out and completed in July 2008 were presented to the site in a report. It consisted of a presentation of the method used to collect data and analyze the accident, a description of the circumstances of the accident, an analysis of the accident analyses conducted by the EDIA refinery and Rex teams and, finally, a presentation of the two weak signals uncovered. The report did not have any elements deriving from the study of the normal functioning, as we did not have time to process that data before making the report.

It was submitted to and commented on by the site manager, the production manager and the head of the quality service. The comments were fed back to me (sitting on my own, without support from the supervision team from the university, etc) during a meeting with the head of quality department. This was not a discussion, but rather a detailed feedback of annotated comments on the report, in which I was cast in the role of the student or learner receiving supervision and correction, and not of an equal partner with whom to discuss on an equal footing.

The analysis we had proposed, shedding light on two weak signals identified but not included in the Rex feedback, and showing some dysfunctions in the organizational safety, was not well received or accepted. The comments were largely negative and defensive.

Our hypothesis to explain this is as follows. The EDIA refinery expected the report to be a contribution sticking to the findings of the analysis conducted by the site itself. However, the analysis we provided went further and deeper than these expectations of the EDIA site. The defensive posture could be indicative of rigidity on several levels. First, our analysis of accident opened avenues to be pursued which were stressing the involvement of the managerial line as a whole, and the importance of the informal dimension of the organization in professional practices. However, we found that these channels were not easily integrated in the formal analysis of events, which were often limited to the technological, behavioural and regulatory factors (see section 4.4.2.2) and did not call into question the way in which the organization is set up for normal functioning. The second rigidity is related to the recognition of managerial responsibility in this accident. The difficulty of challenging the view of the responsibility of line management and hence of the site, and the corresponding limitation of the analysis of the accident to technical and human errors, can be interpreted as signs of protection against recognizing this shared responsibility. Finally, the resistance displayed during the first feedback session could also refer to a difficulty to challenge certain of the accepted concepts and practices of the EDIA safety management system, including the detection and treatment of weak signals.

Putting these points together, the difficult acceptance of our analysis can be interpreted as symptomatic of a defensive, rather than a reflective posture of the site faced with a critical analysis of their safety management system and the proposal to learn new practices.

4.5.1.2 Power games

There is another dynamic underlying this feedback, which made this method of feedback, with hindsight, inappropriate for several reasons. Firstly, the setting of the feedback revealed an imbalance of power, in that I, as young researcher, with an academic approach and a non-technical background, was facing an internal company expert on both the technical and safety management areas. This first feedback session was therefore an "assessment" by the company of the first report, in which they were asking for modifications and corrections. The lack of discussion on the method of data collection and the results themselves did not allow me to clearly defend my report. I wanted to facilitate discussion on the basis of this analysis and lead the site to reflect on aspects of the accident that I had highlighted, and on potential actions to be implemented. It must be noted that this session was a failure in this respect, due to its set-up, but it was also symptomatic of a difficulty in the site to accept results that opened new horizons for analysis, especially ones proposed by a non-specialist in technical field.

4.5.2 Second feedback session, a mutual learning process

As a result of the poor outcome of the first feedback, a second feedback session with headquarters employees and representatives from the site was set up. The design and purpose of the session were carefully reviewed with the research team and FonCSI before the session, to avoid running into the same problems as the first feedback (an example of organizational learning within the research team).

The second feedback session was held at the headquarters of the EDIA Group. We had three objectives: to present the results from the case studies (which now included the analysis of the normal operation to back up the accident analysis), to discuss the results and agree on their validity and relevance and, finally, to discuss possible recommendations that could be implemented on the EDIA site.

4.5.2.1 Feedback design and results presented

This feedback session was designed to overcome the difficulties encountered during the first one. We somewhat rebalanced the relative power of the two sides by inviting the research team as a whole (4 members from the university, EDF and INERIS) to support me as researcher, which gave more weight to the presentation of the results. From EDIA, actors were present from different levels of the EDIA Group: the head of the refining branch, the manager of the Rex Team of the refining branch, and a representative of EDIA top management, together with a representative of the refinery site (the head of the quality department). This team combined field expertise and knowledge with that of the broader policy ramifications for the Safety Management of the EDIA site (and other sites). This second feedback session was therefore designed as an opportunity to present the results of the case studies on the EDIA refinery, but more especially to create time for discussion and validation.

The final results of the case study were presented in two ways. Firstly, a final report was submitted to the participants before the meeting. It included an analysis of the accident (the preliminary results of which had been presented during the first feedback session) and an analysis of normal operation. This was the basis for an oral presentation of the results including: the reconstruction and analysis of the accident with the ECFA+ method (Event and Conditional Factors Analysis[30]) a attempt of accident analysis specially made for this presentation (see appendix 8), the definition of the weak signals revealed by the accident analysis and, finally, questions opened up about organizational factors blocking the weak signals, derived from our analysis of normal functioning.

[30] The ECFA+ method is presented in detail on the website www.nri.eu.com

Using the ECFA+ method to assist the presentation had several reasons. It gave a clearer analysis of the accident than the one resulting from the fault tree (appendix 2). We did indeed identify the sequences relevant to the accident and the conditions under which these sequences were linked. It also provided clear links to the questions that were the basis for the discussion after the presentation of results.

During this meeting, we also defined the two weak signals from the accident, namely the blurring of professional practices around the handling of the isolation of the valve and the underestimation of the risk of steam.

4.5.2.2 Validation and relevance of the results

As stated in the introduction, the two objectives of the feedback session were to present and validate the results of the case studies at the EDIA refinery. Two major issues were addressed in the discussion: the definition of weak signals, and learning from the Rex process.

4.5.2.2.1 Agreement on weak signal definition

An agreement on the definition of weak signals was found at the end of this session. The company participants agreed that a number of the informal practices in the context of the valve isolation were weak signals arising from the accident for several reasons. Although they strongly defended the viewpoint that contractors and EDIA coordinators must comply with rules such as work permits, the participants did return again to the question why the subcontractor exceeded the permit and discussed it more deeply, taking account of the fact that the fitter was experienced, was informed of the task that Company 2 would carry out later and knew the risks associated with steam. It was agreed that the segmentation of tasks could lead to practices contrary to safety. The issue of the correctness of the work division was addressed again - here the separation into two tasks and thus delivery of two work permits. This led to the following remark: “*The less there are interfaces, the more there is a continuum in the interventions*" (EDIA Group, top management). However, the division of the tasks as decided on in the case was not really called into question during the meeting. In trying to understand the violation in this case, the company participants came to the consensus that the subcontractor wanted to “do his best" or “be helpful”, which limits, in our view, the understanding of the accident sequence to an issue at the individual human level, more specifically to the behaviour and intention of the individual contractor. The question remained open whether avoiding the splitting up of tasks in such a way would be an effective way to prevent the emergence of professional practices that may affect individual and process safety.

The participants did subsequently recognize this violation as being the result of a normalization of deviant practices. Routinization was identified as a source of risk for which preventive measures

- such as sensibilization (refreshing awareness) of the contractors - can be suggested. Finally, it was accepted that this weak signal of the accident had *"not been identified"* (EDIA Group refining branch manager) through the tools for safety anomaly reporting. This corroborates two results presented earlier in this chapter, namely the relative ineffectiveness of reporting tools to detect data of different natures such as this, and the difficulty to make sense of this information and integrate it into the process of Rex.

4.5.2.2.2 Improving learning

The company participants recognized that data processing is one of the major weaknesses of the EDIA site: "*Reporting tools are independent of each other and little integration is being made*" (EDIA Group, top management). To overcome this pitfall, it seems necessary to integrate information and identify the recurrence of a phenomenon (what we defined as the first step in "sense-making"). The usefulness and effectiveness of these different tools was also raised. Following the results of the case studies, participants acknowledged the weakness in their learning system, in its analysis and use of data from different channels of information transmission. They acknowledged that this difficulty in integrating information would increase the difficulty to process weak signals.

We then questioned the role of the Rex Team and the extent to which this group adds value to analyses conducted by the refineries. We noted in section 4.3.2.2.2 that only events rated 4 and 5 by a refinery could be selected by the Rex Team and be analyzed as a Rex. During this feedback session, the head of the Rex Team for the refining branch said that these practices were already being changed. Now the Rex Team can select events rated 2 and 3 by a refinery. The objective is to take into account not only serious events, but also minor events which may be situated as precursor events that could become a serious accident, in order to manage safety proactively.

The question was also raised as to whether the role of the Rex team of the refining branch should be uniquely to disseminate and share the lessons learned from the analysis of local events, or whether it should also aim to ensure that, locally at the sites, the Rex forms and lessons have been understood and taken into account and that actions have been implemented in the different refineries. The Rex process is still young, and it would seem that methods are still evolving in a double perspective: an improvement of methods of analysis used by the Rex Team, to provide a more obvious added value to the analysis conducted by the refineries, and a supportive role in the implementation of lessons from accidents to use the knowledge learned from the experiences of other sites.

4.5.2.2.3 Recommendations: failure of action-research or participants reluctance?

Finally, we return to a reflection on the action-research process. This includes, in addition to the diagnostic phase, feedback and validation of results with the sponsor, and recommendations for actions (see section 3.3.2).

In contrast to the first two objectives (discussion of the results and agreement on their validity and relevance through presentation of the results from the case studies) which we were able to achieve in part at least, we were unable to adequately lead the participants to reflect upon action. The second feedback session was limited to a discussion of the weaknesses and strengths of the safety management (and particularly information processing) systems and did not move on to proposing concrete actions. The reasons for this unfinished Action Research will be addressed further in chapter six.

In conclusion, feedback sessions revealed the importance of designing the session and the presentation in such a way as to promote not only a strong presentation of results but also a level playing field of power, to provide an opportunity for discussion. This was finally achieved in a context involving the entire research team - rebalancing roles and power relations - and actors from different hierarchical levels and functions of the EDIA group. This cross-pollination of points of view between the industry sponsor and the research team enriched, in our view, the second feedback in particular. The attitude of each participant showed clearly a willingness to hear the analysis we were outlining and to discuss the weakness of information treatment and the Rex process in the company. The second feedback session was a chance to experience what we have called in the Methodology chapter “mutual learning” during which the research team and the company participants tried to reach agreement on the validity of the approach and results and the lessons to learn from a study conducted by a researcher.

4.5.2.3 Conclusion of Chapter 4

The first and second parts of this chapter, devoted to the analysis conducted of an accident at EDIA, led to the identification of three weak signals: latent and repetitive technical anomaly, the segmentation of tasks between the two subcontractors and between them and the EDIA staff, generating adjustments of the formal rules and the use of informal deviant practices, and an underestimation of the risk of steam. These three pieces of information, although known, revealed shortcomings in the organizational management of safety, and were not thoroughly investigated (especially in the Rex process).

The third part of the chapter was designed to examine the origin of the emergence of these blockages to weak signals, thanks to the study of normal operation. Three organizational characteristics were then identified as "sources" of the blocking of these weak signals. The first was the organizational complexity, characterized by:

-The methods of sub-division of the tasks of subcontractors and the distinction between the production line and the staff sectors.

-A double fragmentation of safety management: a distinction between operational safety and procedural safety and, within the safety management system, a fundamental challenge to link and treat data related to safety coming from different sources and channels without any common model or philosophy.

We then described the EDIA communication models, in particular the role of technical or organizational filters in the communication chain of detection, transmission and reception. These filters have two roles. They can amplify data that fits with the formal system of information management and block others not designed to be treated in the same formal system.

Finally, we described an organizational learning system largely limited to a first level of learning (organizational single loop), resulting from the first two organizational characteristics.

If we agree that weak signals are fragmentary information - requiring to be linked with other information sources in order for sense to be made of them - and dissonant or “exceptional” information, falling outside the "rigid", information management system based on already defined classification systems specifying the information to be reported and taken into account, then we can conclude that the organizational characteristics we have identified will be major obstacles to the processing of weak signals.

-To be able to take account of weak signals of accidents requires the establishment of a method, as the model of Hale (2000) proposes, in order to:

-Give sense to data by selecting those which possess informative power, based on their place as indicators of deviations within accident scenarios

-Open up predefined and closed analysis categories by including data going beyond current categories (introducing categories for unspecified and unexpected surprises) and recognizing the value and legitimacy of informal channels of transmission and reception of information about them

-Anchoring this method in the SMS so that the learning loops are regularly assessed and adjusted, thanks to a system of formalized organizational learning, which assesses the match between available resources for monitoring deviations, the relevance of these indicators and the need to review the type of information and of communication models that should be mobilized to process the information.

The final section of the chapter dealing with the feedback of results to EDIA raised several questions. First we discussed the design of such sessions and showed that, as part of action research, feedback sessions should ensure both a symmetry of the position, power and roles of the participants (research team and sponsor), and ample time for discussion and mutual learning based on confronting the technical and practical expertise of the industrial sponsors with the in-depth analysis delivered by the research team. The evaluation of the success of the action-research that we conducted will be performed in the final chapter six.

The second case study, conducted on ACIO will be presented in next chapter. Although in some respects less detailed in the information collected, this second case enables us to test the hypotheses from the EDIA case study, before generalizing the results in a final summary chapter.

5. ACIO case study

5.1 Introduction

The second case study was conducted on a steel plant we call ACIO[31]. We accessed and collected data thanks to the collaboration of the safety service of the site.

First, we will briefly present the ACIO site: the organization, management of safety at the workplace and the policy of preventing major accidents. The second part will be devoted to the analysis of three accidents. We will describe the circumstances of the accidents and Rex process conducted by ACIO. The third part will return to deal further with the normal operations of the (safety) management system. We will try to understand where and how the weak signals of an accident are rooted in normal operation. The fourth part will be the evaluation of the methodology applied in this research, particularly the issue of partial completion of the action research.

Data collected on the ACIO site will be compared as we go along to those derived from the EDIA case study in chapter 4. Our objective is to identify similarities but also differences between the two learning systems that we studied.

5.2 Presentation of the ACIO site

5.2.1 Site structure

The ACIO site is part of an international steel manufacturing company. The main customers of this group are companies working in automobiles, construction, household appliances and packaging. The site produces over six million tons of liquid steel per year, has over 3,600 employees (subcontractors and ACIO employees) and covers a distance of 6 km from west to east and 2.5 km from north to south. The site comprises two factories: the ACIO factory dealing with hot steel and the Spiker factory located 1.2 km from the ACIO site that receives and processes cold steel (this site is not part of our study).

[31] As for EDIA, we changed the name of the company to make it anonymous.

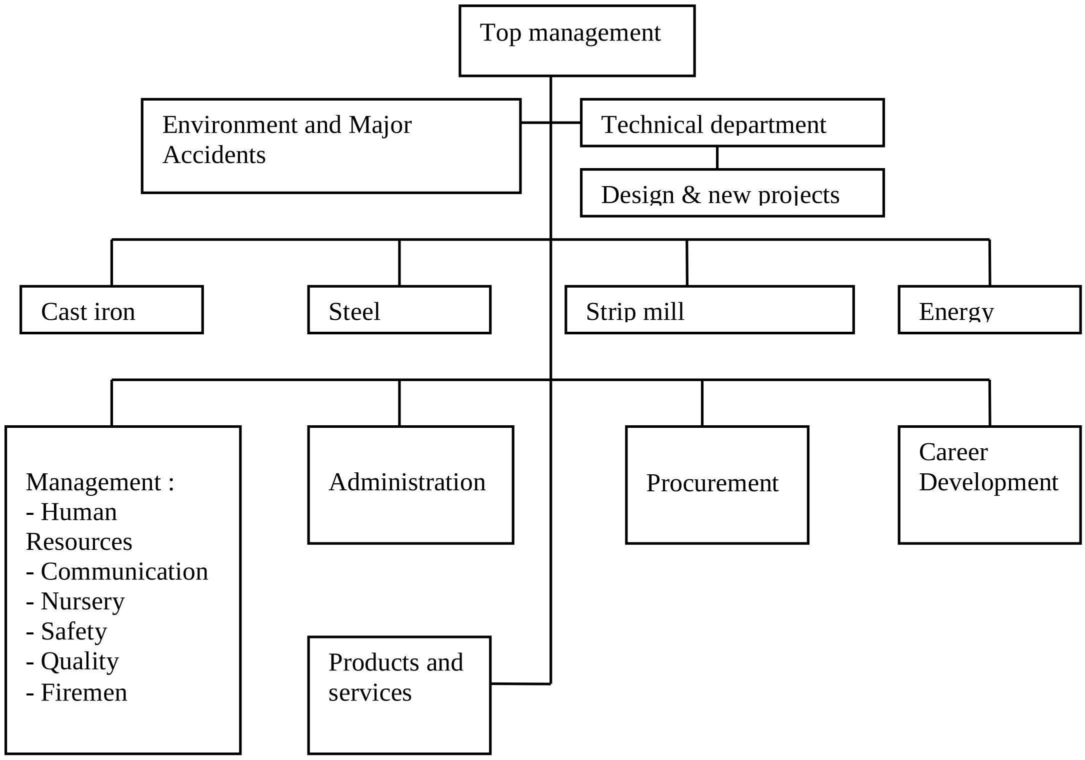

Figure 19: ACIO organization chart.

The organization of the ACIO site is slightly more complex than that of the EDIA refinery but also here we find a structure in two dimensions:

-A line area consists of 4 departments, cast iron, steel, the strip mill and energy. The four operational departments are interdependent, because they each represent a link in the process of steel making (described in appendix 9). Each business unit is divided into two main entities: operations, which support the operation of facilities, and maintenance, whose responsibility is to detect technical anomalies and supervise maintenance work performed by subcontractors.

-Staff departments comprise the technical department, design & new projects, the major accidents & environment service, procurement, administration, human resources and other management services, including safety. These are attached to top management and independent of the operational business units.

The descriptions in the following section specifically address safety management.

5.2.2 Safety management

Safety is divided into two entities: the safety service responsible for safety and health at the workplace, and the service responsible for prevention of major accidents, which are to be found in different departments.

The safety service is divided into two areas: occupational safety and industrial safety.

-Occupational Safety: ten preventionists work full time in the service. Although hierarchically linked to the safety service, seven of the preventionists are assigned to the different operational units. They maintain, through prevention and information actions, the level of safety in the operational units to which they are assigned. The other three preventionists each have a more specific function: one works in the design department, another is devoted to occupational diseases and the management of Personal Protective Equipment (PPE) and the third to the relationship with contractors.

-Industrial Safety: this includes the regulation of carcinogens, mutagens and reproductive toxic products and hazardous chemical agents, preventing fires, explosions and gas leaks, and intervention in case of fire (provided by the Fire Department and the security guards). The preventionists of this department are only marginally involved in event analysis and learning, so we do not deal with them further in this chapter, apart from noting this as another example of fragmentation even within the Safety Service.

Two types of meetings are organized by the safety service. A daily meeting, run by the deputy head of department, gathers the preventionists together. The latter report incidents or accidents that have occurred during the day in the operational units. A weekly meeting run by the head of the safety service presents the weekly results on safety, runs through the objectives of the safety service (number of audits to conduct, etc.), the OHSAS developments and the implementation of specific safety actions such as information dissemination on safety, Rex forms etc. Preventionists also participate in the weekly meetings organized by the operational unit to which they belong (this link will be discussed in section 5.4.2 of this chapter).

Preventionists use a number of tools: information tools, prevention tools (or anomaly reporting forms such as behaviour audits) and Rex forms. All these tools will be presented and analyzed in Section 3 on normal operations. Since 2007, the ACIO site has been implementing the OHSAS 18001 safety management approach to consolidate and harmonize all the existing tools in a process of analysis and prevention relating to safety and health at work. This approach is clearly differentiated in the company from the Safety Management devoted to preventing major accidents.

5.2.3 Major accidents management

The site is classified as an upper level SEVESO site, because of its storage of a large quantity of water treatment products containing chromium, as well as oxygen and gas (the gas holder contains 332 tonnes of gas against a prescribed limit of 10 tonnes). Therefore ACIO must develop and implement a policy to prevent major accidents. The latter is divided into the following steps:

-Preliminary Risk Analysis (PRA)[32]. 625 risks have been identified by the preliminary risk analysis: 132 at the steel plant, 42 in the Matagglo department, 100 in the blast furnaces, 10 in the energy department, 166 in the coking plant and 34 in the strip mill.

-Modeling scenarios of major accidents. Based on the preliminary analysis of risks, and according to a matrix of the occurrence and severity of the hazard studied, 17 major accident scenarios have been defined. A major accident is defined as "*An occurrence such as a fire or a major explosion resulting from uncontrolled developments during the operation of a facility or dangerous preparations, causing serious and immediate consequences, reaching beyond the boundaries of the facility*" (Source: Training for Major Hazards, ACIO, 2006). For example, a scenario identified in the steel making department reads as follows "*Steel Plant Gas Leak following a breach of the scrubbed gas pipeline"*. Its severity is listed as 5 and the probability of occurrence as 2.

-Bowtie. Each major accident scenario is then modeled as a bow tie. It clearly identifies the causes of a scenario, safety barriers (prevention and protection) and, finally, it models the potential consequences of the scenario.

-PPRT (Plan de Prévention des Risques Technologiques - Plan for Prevention of Technical Risks required by the Law of 2003). The calculation of toxic effects and their extent is performed for each scenario.

-The Important Elements For Safety or EIPS [33] are defined according to the PRA and are subject to special monitoring conducted by the operational units.

Occupational safety and prevention of major accidents are the two major dimensions of safety at ACIO, but are managed independently by two different services. We will see to what extent this distinction may have effects on weak signal treatment.

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32 "The preliminary risk analysis (PRA) is to identify situations of risk associated with each task, identify the causes and consequences of each hazardous situation, identify internal and external targets, identify safety barriers for prevention and protection associated with every dangerous situation, rate the risk severity and probability, identify major risks, choose Important Elements For Safety (known from their French abbreviation as EIPS - Eléments Importants Pour la Sécurité) and study possible improvements" (Source: Training in Major Hazards, ACIO, 2006).

33 EIPS (Elément Importants pour la Sécurité) may be equipment (valves), safety devices or groups of safety devices, tasks, operations performed by an individual, procedures (training) or parameters. The selection of items is made by the operator (company), in conjunction with the PRA, with a view to controlling major hazards in all phases of facility operations, including degraded operations. The EIPS should be available, reliable, testable, and be subject to special monitoring "(Source: Training in Major Hazards, ACIO, 2006).

5.3 Accident analyses

In contrast to the case study conducted at the EDIA refinery, we analyzed accidents that occurred in each of the six operational units.

-Accident 1. During maintenance work, involving a significant coactivity between several subcontractors, an operator of one of the subcontractor companies narrowly avoided getting crushed by a steel transfer truck. This potentially fatal near miss revealed a problem of coordination and communication between ACIO employees and subcontractors, and a problem with equipment lock off (of the steel transfer truck).

-Incident 2. Following a fire in an oxygen hose, which caused a major leak of oxygen, two operators operated an isolation valve and, despite the risks of this intervention, managed to stop the leak and prevent a new outbreak of fire.

-Accident 3. Following infiltration of moisture, a product that we have named Alpha[34], stored in a silo, reacted to form Gamma. This reaction led to self-ignition causing the explosion of the silo.

-Accident 4. Following a cleaning operation, a tar separator was restarted. An explosion, caused by the presence of air, gas and electricity, led to a partial destruction of the equipment. The accident analysis identified an abnormal penetration of air, and called for an overhaul of the tar separator casing.

-Incident 5. A forklift truck struck a rack whilst carrying an empty steel vessel to the maintenance department.

-Accident 6. Fire in a gas mixing station following a maintenance operation on a valve.

Only the first three cases were selected for deeper description and analysis in the next section. These three cases appeared attractive for several reasons. Firstly, they were analyzed deeply by the ACIO site, including a fault tree analysis, together with an analysis and recommendations proposed by an external organization (accidents 2 and 3), a Rex notice(shared with other ACIO sites) and also for cases 2 and 3 a special meeting of the CHSCT (Company Safety & Health Committee) and finally proposals for actions to be implemented to solve the problems identified. Secondly, our analysis of the Rex forms showed that the company analyses nevertheless seemed to be limited to the technical and procedural dimensions, and that the lessons learned from the accidents were focused on new knowledge about the products used and/or the technical processes in the installations.

The three analyses allowed us to define, identify and classify three categories of information which were poorly taken into account in the Rex forms:

34 For anonymity reasons for the site, we have changed the names of the products used by ACIO.

-Persistence of latent technical defects: identified but not treated

-Persistence of defects in coordination between subcontractors and ACIO employees, resulting in informal practices that may threaten safety

-Persistence of poor assessment of risks which could cause blindness to the potential or confirmed risks.

The other three cases, although analyzed, were not selected for detailed presentation here, firstly because the analysis of the first three cases proved rich enough to generate interesting conclusions about the learning system on the ACIO site without adding more overlapping data to be ploughed through to reach the same conclusions. Also the other three cases were technically more complex, and would have required considerable effort on our part to investigate and understand the facts in sufficient detail. This was made more difficult because of gaps in the data available on these other cases. So, for the sake of clarity and simplicity we have restricted the presentation to the first three cases. But even if we do not explicitly mention them, the other three have participated in our understanding of the technology and learning system of ACIO. We turn in the next part of the chapter to the three accidents.

5.3.1 Accident 1: subcontractor's coordination during maintenance work

Defined as an occupational accident by the ACIO site, accident 1 nevertheless raised two interesting organizational dimensions, similar to those discussed in the analysis of the EDIA refinery accident:

-Difficulties in the context of the work to coordinate the tasks of the subcontractors, while strictly complying with safety procedures

-An underestimation of risks.

The other interest for us lies in the two analyses which were conducted by the site:

-An "official" analysis following the procedure defined by the ACIO site after an accident

-A complementary analysis. As I was both witness and communicator relaying information on this accident, I undertook, together with a preventionist, to clarify the circumstances of the accident, which had remained throughout the formal analysis both vague and incomplete. My role as researcher and participant will be raised at the end of the chapter, and in particular the contributions of my involvement in the lessons learned by the site from the accident.

5.3.1.1 Circumstances of the accident

5.3.1.1.1 Maintenance work

The accident took place during maintenance work on the refractory bricks of steel converter 1[35]. This work was to replace the bricks of the converters that were in the process of wearing out during the converter operations. It was therefore preventive maintenance. During the work, the other two converters (2 and 3) remained in operation, but maintenance was planned to be made on them at the end of the work on converter 1. Work on the three converters lasted in their entirety 71 days and took place over a period of eight months.

The organization of this brick work was extremely complex. Because the work lasted seven days, the steel making department took the opportunity to perform other work on the sector at the same time. Thus, maintenance work was being carried out on the oxygen lance, the boiler external to the converter, product additive apparatus and the dust collection. This required the work of 35 subcontractors, with over 500 tasks.

5.3.1.1.2 Steel transfer trucks (STT)

Steel transfer trucks (STT) carry loads of slag for conversion across the shop floor of the converter hall. They are guided by an operator located in a control room. There are electrical relay stations on each side of the rails of the STT. These stations locate the position of the truck and stop and start the STT as well as ensuring the locking down and unlocking of the truck. These stations are located at the back of the hall (on the ground) in a dark, dusty, noisy and dangerous area.

Slag deposits fall regularly on the path taken by the STT. They are picked up by a bulldozer equipped with a shovel to clear the path of the STT. Bulldozers may be driven in two ways: remotely – an operator guides the bulldozer using a remote control - or manually, the driver sits in the cab and drives the bulldozer and the shovel to pick up slag deposits.

5.3.1.1.3 Work preparation and organization

The preparation of the brick replacement works began twelve weeks and three days before the first day of work relevant to this accident. A project manager – an ACIO employee - was appointed, assisted by a "planning" manager - employee of a subcontractor company.

The preparation work included:

- -The completion of planning for the work on the converter,
- -The development of a Prevention Plan (PP), which is designed to identify precisely the tasks that each company will realize during the project. The head of the PP has the responsibility

[35] Refer to the description of the process of making steel in appendix 9.

to check the risk analysis prepared by the subcontractors themselves and to look after own staff safety,

-The organization of a meeting with the companies prior to the project start, whose aim was to present to them their places of work, their tasks, conditions and time of work,

-A field visit with the subcontractors.

During the seven days of works on converter 1, two activities ensured the monitoring of the project. Firstly, the project manager went every morning between 8.00 and 9.30am to the control rooms in the units where work was being performed, in order to receive reports about any incidents and anomalies of the day before. Then a “works meeting” was held every morning at 10.30. It was run by the project manager and the planning manager, and attended by all of the subcontractors. Its aim was to run through the day activities and any possible incidents and to ascertain whether the work was running to the planned time according to the schedule. If not, the project manager was responsible for changing the schedule and the associated work permits. A report was prepared after each meeting and forwarded to the head of Steel Plant department[36].

Work on the converter was divided into areas. For each, an ACIO zone manager was appointed to supervise the work performed by contractors.

5.3.1.2 Coactivity between three contractors

5.3.1.2.1 Accident circumstances

On the day of the accident, three operations were planned in the area of Steel Transfer Trucks (figure 20). Company 1 (C 1) was working on the electrical stations, company 2 (C 2) was driving the bulldozer and company 3 (C 3) was cleaning out the trenches, running the length of the area on either side of the pathway for the STT.

[36] Developing a Plan for Prevention and work permits will be described in Section 5.4 on normal operations.

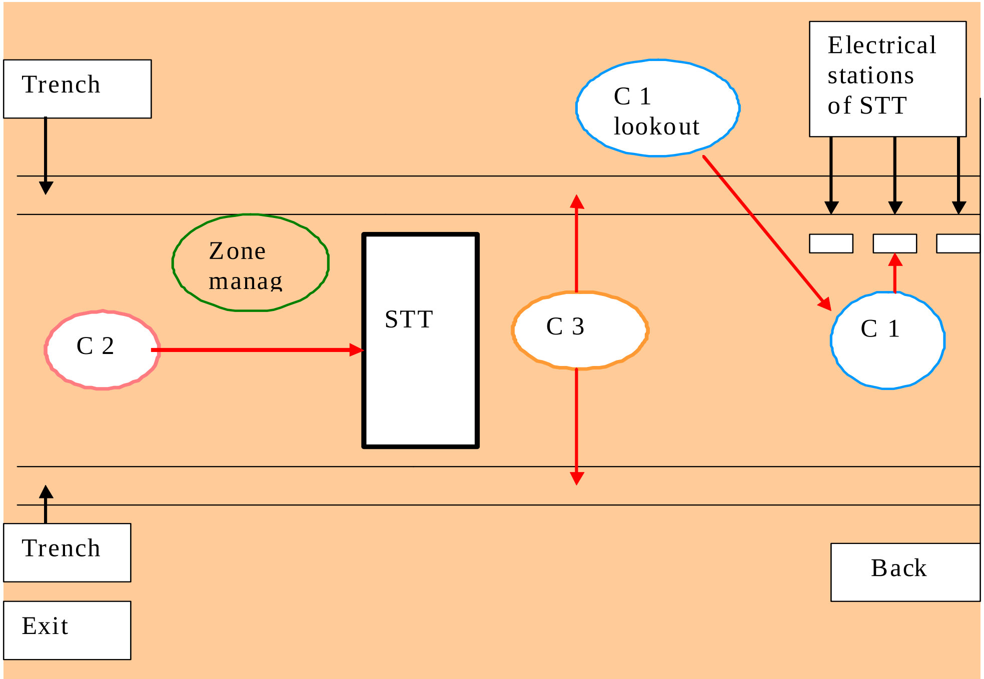

Figure 20: Area of accident 1, ACIO.

Legend: Red arrows indicate actions/workplaces of the three companies.

On the day of the accident, three activities were planned on the schedule – see figure 21a:

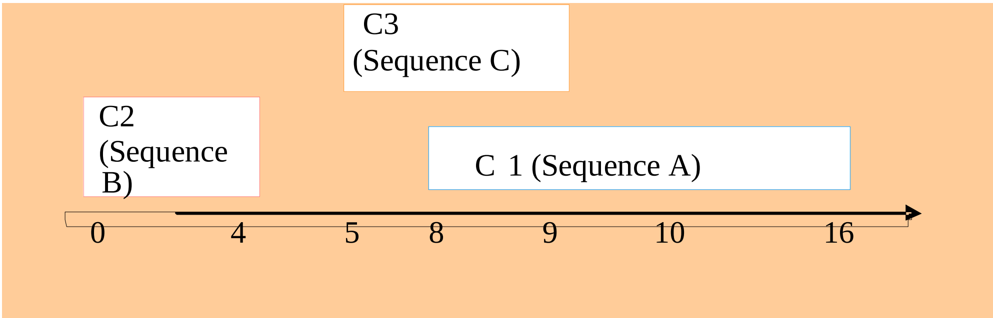

Figure 21a: Accident 1 initial planning, ACIO.

The arrow indicates time from midnight (0) to 16.00 (16).

The main sequence (A) consisted of maintenance work on the electrical stations of the STT by Company 1, which was scheduled from 08.00 to 16.00. A second operation (sequence B), from midnight to 04.00, consisted of moving the STT (by Company 2) to clear the way and allow Company 3 (sequence C from 05.00 to 09.00) to clean the trenches along the edges of the STT pathway).

During sequence A, C1 had to operate in the STT area, as indicated in the schedule and in its work permit. Three operators were involved: the first two worked on the electrical stations whilst the third, as lookout, stood back from the operation with a yellow waistcoat on to watch (with a whistle to warn his colleagues in an emergency). The lookout is a necessary safety measure because the area is very noisy; an operator working on the electrical stations and equipped with earplugs cannot be expected to hear any approaching danger.

However, in practice, the bulldozer company (C2) carried out its work between 09.00 and 10.00 (Figure 21b).

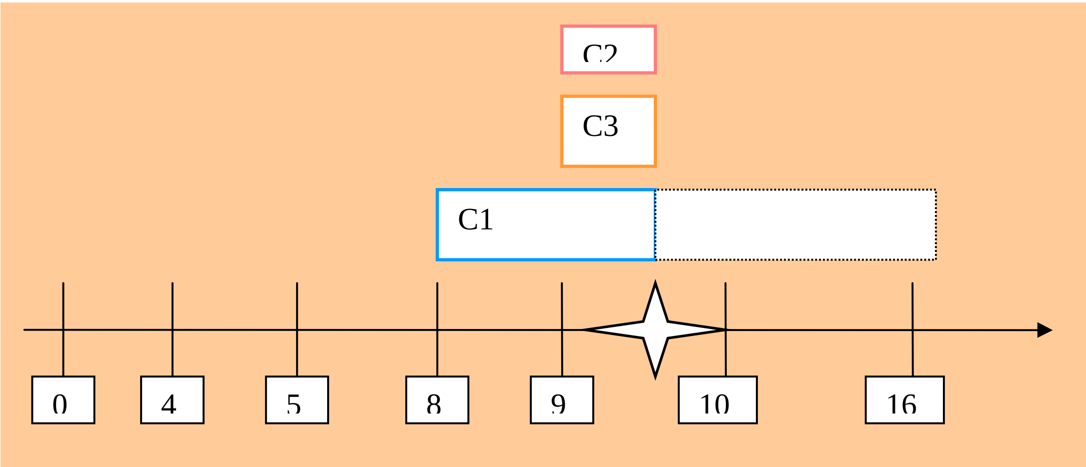

Figure 21b: Accident 1, planning changes, ACIO.

The arrow indicates time from midnight (0) to 16.00 (16) and the star is the approximate time of the accident.

The driver saw the operators of C3 who cleared out of the way. He then pushed the STT easily with the bulldozer, because it was not mechanically locked off, towards the back of the hall, where C1 was working. The bulldozer was being driven from the cabin (rather than remotely), which meant that the driver had no visibility of anything behind the STT he was pushing. The lookout of C1, equipped with his whistle and seeing the STT moving forward, warned his colleague working on the stations to get out of the way. The bulldozer driver was told to stop his maneuver immediately[37]. In this way the crushing of the one of the operators of C1 was avoided.

[37] We have no data allowing us to identify who ordered the halt of the bulldozer's maneuver.

5.3.1.2.2 Failures of work coordination

We note two failures. As we have seen, the schedule of operations for C2 and C3 had been changed; they should have worked earlier. The zone manager, responsible for coordinating operations, had nevertheless allowed C2 and C3 to work during the time period of sequence A without considering the safety of C1.

We discovered later that the zone manager was not present at the time of the operation of the bulldozer driver. Indeed, he was attending the daily works meeting that was taking place some distance away from the accident area and began exceptionally on that day at 10.00 (not 10.30, see section 5.3.1.1.3). The operation of the bulldozer, between 09.00 and 10.00 was therefore not supervised by the zone manager because he had already left to attend the meeting.

5.3.1.3 Information transmission and event analysis

The following sections present the way in which the information related to the accident was handled in the company. We will show how the information was detected and, transmitted, analyzed and processed by the ACIO site.

5.3.1.3.1 Transmission of information

The information was reported for the first time during the works meeting on the day of the accident. The accident had just taken place between 9 and 10am and the meeting was held from 10.00.

When the project manager got to the point of discussing the work on the trenches alongside the STT area, the team leader of C1 (who was not the victim) intervened to explain the circumstances of the accident. He explained that, as stated in the work permit, his operator was carrying out preventive maintenance on the electrical stations of the STT. However, the bulldozer driver pushed the STT "*without asking himself if there was someone in the way.*" He made clear that the STT should have been mechanically locked off and that the area should even have been cordoned off. The zone manager (who was present at the meeting and was not at the accident site) admitted that the bulldozer should not have pushed the STT. The project manager and planning manager acknowledged the information and noted it in the meeting report.

Following this meeting, the project manager and the planning manager completed the meeting report. The standard form provides space for three indicators of "satisfaction" (see appendix 10): safety, scheduling and organization. The event raised during the meeting (as a near miss) was noted in the box "safety" and described as follows: "*STT near-accident, the STT was pushed by the bulldozer while personnel of company 1 was present in the area*". Then, the two managers started to sketch an explanation in the box "organization". They wanted to indicate that safety was an issue to be resolved between the ACIO employee responsible for giving the orders (zone manager) and the person responsible for the work. But, as they had very little information, they decided to erase their draft and leave the box blank. Once the report had been transmitted, the Steel Works Department took the decision to set up an analysis of the accident.

As a final step, after the works meeting – which I had attended, I reported the information to the safety service. As the preventionist assigned to the Steel Works Department was absent, I spoke to the "interim" preventionist. He asked the mechanical maintenance sector of the Steel Works Department to inform us as soon as an accident analysis would be organized. We were therefore placed in the loop for the analysis of the accident.

My intervention helped to accelerate the transmission of information (although the preventionist would have received the information anyway by another channel).

5.3.1.3.2 Official investigation first step: event analysis

The accident analysis was carried out at two levels:

-A formal process in three stages: a meeting for the accident analysis, a meeting to develop the fault tree and one to develop the Rex form,

-A complementary process: the preventionist and I undertook an analysis which was as thorough as possible, in order to identify clearly the organizational causes of the event.

A preliminary analysis of accident was carried out five days after the event by the mechanical maintenance service of the steel works department. It was attended by:

-Operational personnel: the zone manager of the area where the accident occurred and an ACIO technician from the converter 1,

-Maintenance personnel: a technician from the ACIO electrical maintenance (who chaired the meeting) and the head of the mechanical maintenance service of the department,

-Contractors: the victim of the accident and his team leader (who had reported the information at the works meeting). Companies 2 and 3 were not present. The reasons for this were not mentioned, but we can make two assumptions: either the two companies were not available or their presence was not considered as relevant (company 3 was only a witness). However, we believe that a meeting between all actors concerned with the accident would have allowed better sharing of information and a more in-depth analysis of the event.

-Finally, the preventionist and I, who was presented as a "trainee" at the safety service.

The team leader of C1 related the facts; namely that on the day of the accident the bulldozer driver pushed the STT, while two operators of C1 were working on the stations of the STT. He raised the central issue: was the bulldozer operation an error in planning or a failure to follow the work schedule? Two main points were raised that we categorize as follows:

1. A change in planning was not notified

*The coordination of subcontractors

The Prevention Plan, made and owned by all of the subcontractors, stated that, during refractory brick works, any changes to the original schedule must be forwarded to the zone manager who would transmit the information to the daily works meetings. Changes must be made the day before in order to make a new risk analysis of coactivity between subcontractors, and deliver new permits to work. If the change to the schedule of C2 (bulldozer) had been planned, C1 would not have been allowed to work that day; thus staff safety would have been ensured. However, the change of time for the bulldozer operation had not been notified. The limitations of this procedure were raised by the zone manager who indicated that he finds it difficult to follow this procedure strictly in a context where completion deadlines are very tight.

*Access to the area of work: the work permit

The driver of the bulldozer pushed the STT during time sequence A, although he was planned to intervene in sequence B. The zone manager would have given permission to C2 to push the STT much earlier that morning, but the bulldozer driver did not carry out the action immediately. The area manager, who attended the works meeting at 10:00, was therefore absent and could not supervise the work of C2 who, without any explicit reason, made his intervention in the absence of the zone manager.

*Supervision of works: the role of the zone manager

The zone manager’s role is to supervise operations in his area (in this case the operations of companies 1, 2 and 3). However, the zone manager was absent when C2 operated. The procedure for the coordination meeting (specifically designed to manage planning changes) did not provide for a replacement of this person while he attended the meeting. Is it therefore adapted to the reality of work?

2. The safeguarding of equipment and facilities

As the STT was not locked mechanically, the bulldozer had no trouble to push it. During work on this area, the procedure requires that the STT must be locked both electrically and mechanically, using a shoe, and the area should be cordoned off (as suggested by C1). The discussion at the meeting furthermore revealed that this is an action that has become habitual. C2 regularly pushes the STT if needed, even if it is electrically locked. The issue of the mechanical lock was therefore discussed. A shoe or pinch-rail that appeared to be obligatory, as we indicated earler, would have avoided the bulldozer being able to push the STT easily.

The lookout played a fundamental role. The initial role of the lookout was not to monitor the STT but the overhead travelling cranes. Although we were not able to track down sufficient data to prove it, we were informed that the lookout was a safety measure to alert personnel working in the STT area if ore or a slag pot dropped from the cranes above. However, the crane lookout was able to alert the operators of his company to the risk of crushing by the STT. It allowed the operators working on the electrical stations to avoid the fatal accident. The original function of the lookout was redefined in the circumstances of this accident.

5.3.1.3.3 Official investigation, 2nd step: fault tree analysis and recommendations

The building of the fault tree was carried out two days after the accident analysis meeting, seven days after the event. It had two goals. First, it aimed at completing the analysis by the presence of C2 (the driver of the bulldozer and the manager of their QSE[38] department). Neither C1 nor C3 were invited to the meeting. We assume, but this remains a hypothesis, that the team leader of C1, who had reported the incident in the earlier meeting, had too much information about the circumstances of the incident which was a "threat" to the ACIO site (we will say more on this later). Regarding C3, the reason for its absence during the two meeting remains unresolved.

Secondly, the meeting aimed to develop the fault tree, a draft of which had been prepared by the preventionist and I, and formed the starting point for the fault tree meeting (appendix 11). Before the meeting, the preventionist and I developed this fault tree on the basis of a method used on the site. It proposes an analysis of the event in the following sequence:

-Reporting the facts: favouring a "good communication" between the transmitter and receiver,

-Identifying the causes of the accident: physical, environmental, technical and organizational,

-Identifying the chain of causes, starting by identifying the final event and working backwards to find the causes of that event and each previous one. Sequence of events, disjunctions and conjunctions are the three types of relationships between events and facts that can be built into a causal tree.

We drew a fault tree showing the conjunctions between facts that constituted the event. Several facts or circumstances were necessary for the ultimate event to occur, notably:

-The material cause: STT was pushed one day after the date specified in the initial planning,

-The organizational cause: coordination between companies 1 and 2 was not carried out well.

During this exercise, the preventionist and I were clear that the organizational cause had played a key role in the accident sequence. I made sure that it was taken into account in the fault tree that we developed, in order to discuss this issue during the fault tree meeting.

The fault tree built by the preventionist and myself formed the basis for the second step in the official analysis. It was completed during this meeting, which clarified the following circumstances of the accident.

[38] Quality, Safety & Environment.

1. Coactivity: risk analysis not conducted

The day of the accident, the STT was poorly positioned, i.e. it had not been moved in such a way as to make the work zone safe for C1 and C3. The bulldozer driver had received the instruction to push the STT. He moved the operators of C3 out of the way, but did not see C1 working on the electrical stations. The zone manager, who was absent while C2 was operating, had not verified the presence of operators in the way.

First, we learned during this meeting that C2 was only available for a limited time and not that specified in the planning:

« The loader is only available at very specific times. When he is there, we use him immediately. The zone manager asks for the operation, but company 2 does not carry it out immediately" (Steel Works operator).

Thus, when C2 was on the site, in general, ACIO would ask the company to operate immediately, no matter what the planning had been. That day, therefore, C2 was available at that specific time and in this situation the zone manager asked him to push the STT. This information confirms therefore two elements:

-The delay in operating. If C2 was not available in time sequence B, but only during sequence A, ACIO had to adapt the work to the availability of the bulldozer driver and set him to work immediately. This produced a delay for C3's work. In this context, it seemed to be difficult, or even impossible to deliver a permit to work "on the run" (the procedure was too complex and long and the PTW must be issued on the eve of an intervention).

-Secondly, if C2 operates during time sequence A and not B, and there is no coordination done by the area manager with C1 and C3, we can understand why the bulldozer driver did not check for the other company's presence on the STT tracks at the back of the hall. He did not have any information about ongoing works and did not know that subcontractors were working in this area.

2. An operation considered as benign: the perception of risk

Although electrically locked off, pushing the STT with a bulldozer had become a routine operation according to the bulldozer driver. The ACIO steel works operator, attending the fault tree meeting, specified that this operation "*pousse-pousse*" is considered "*benign*" and did not require, in his view, a change in the project planning.

3. Work in a context of pressure: environmental cause

Finally, several meeting participants discussed the context of work pressure:

« But I would like to raise the issue that, in order to reduce the time for stoppages, the guys have their heads full. Before we did the stops in 8 days, today it is in 5. We have to do more in less time. On the site there are more people and we have a pressure to get on with it. That isn't only here at ACIO, but on all sites in genera"l (Company 1)
« There are 500 tasks during a refractory brick job, with thirty odd sub-contractors, either on contract or intervening in an exceptional way. We make sure we respect the planning to take account of coactivity". (Steel Works Operation)

The requirement of such work creates pressure on time for the work and for the return of facilities to operation, whilst still meeting the principles and practices of safety -managing coactivity, notifying any changes in planning and delivering new work permits. However, participants noted the difficulty in reconciling these two requirements.

Despite the identification of these three causes, which reveal the organizational dimension of the accident, the recommendations did not really, in our view, address the problems identified. The recommendations were limited to a restatement of the procedure - to notify any change of schedule-, to the creation of another procedure to clarify the zone manager's role, to the requirement to lock off the STT and to clarification of the role of the lookout. These were not sufficient to draw the lessons from the accident. The issues related to the coordination of the subcontractors and the perception of risk were not addressed in the recommendations.

This meeting raised three issues. First, the meeting did identify the circumstances of the accident and also the causes or, more precisely, the conditions necessary for the ultimate event to occur. These conditions, we have seen, were both material and organizational. Secondly, I fulfilled the role of "action-researcher" as I ensured that the organizational factors of this accident were identified and discussed during this meeting. Finally, the recommendations from the meeting, which were restricted to a call for compliance with procedures, reflect the limits of learning in the company.

5.3.1.3.4 Official investigation, third step: Rex notice

Finally, a Rex process was conducted for two reasons. First, this accident was a serious event; the death of an employee of a subcontractor was narrowly avoided. Secondly, the lessons to be learned from this accident were of a generic nature, suitable to be shared with other ACIO sites (which is the objective of Rex forms).

I actively participated in the construction of the Rex notice with the preventionist assigned to steelworks department. The Rex notice was made on the basis of the circumstances of the accident and the recommendations defined during the fault tree meeting. The issues related to coordination between the subcontractors and the zone manager (including the updating and verification of work permits) were not raised here either.

The objective of the Rex notice is to share, throughout the site and other ACIO sites of the Group, clear and concise information, identifying the main causes and the actions to solve the problems identified.

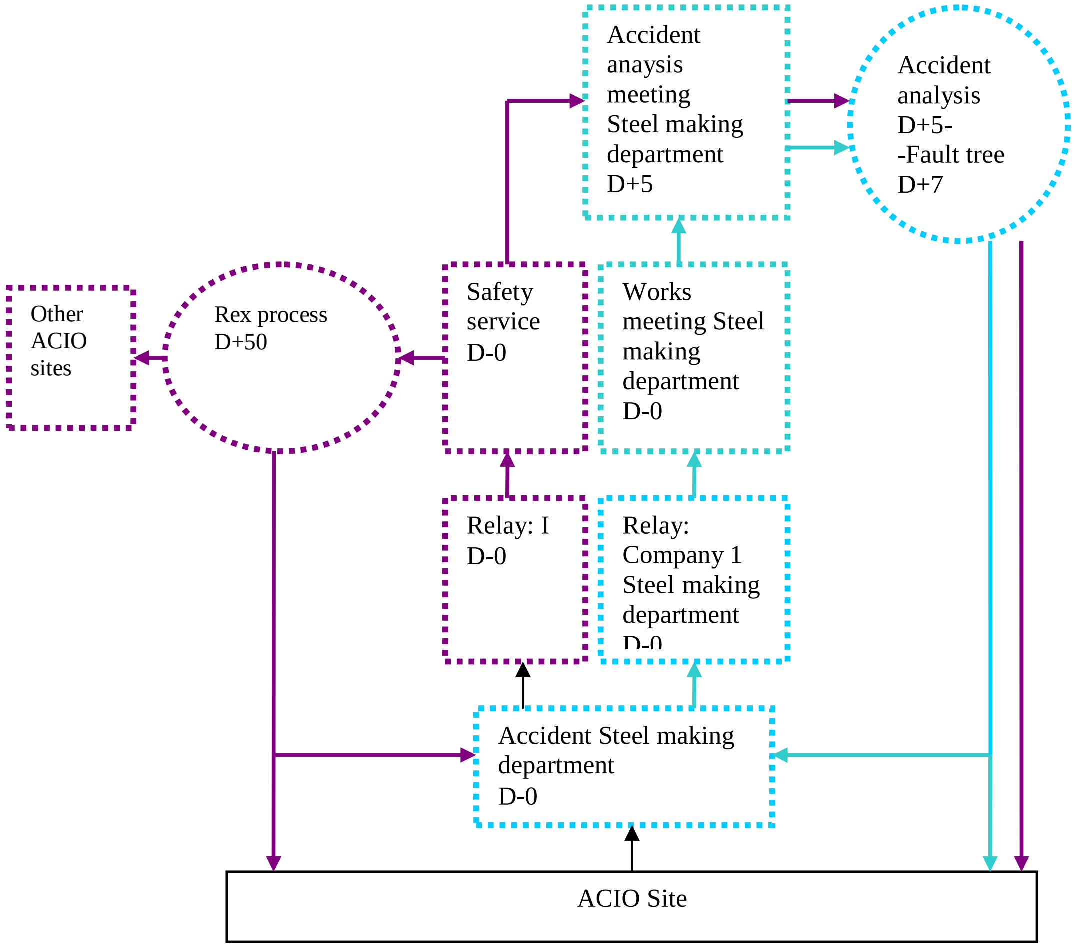

Figure 22: Reporting, analysis and sharing of information: the Rex process, ACIO.

Legend: blue cycle: steel works department; purple cycle: safety service.

5.3.1.4 The limits of the event analysis

5.3.1.4.1 Coordination between contractors and ACIO: from formal organization to necessity to define informal rules

Although the accident analysis and the Rex notice identified several accidental causes, some questions appear not to have been addressed.

Several issues relating to the coordination of subcontractors appear to remain unresolved. Two questions could have put participants back on the track:

-Why is the zone manager not replaced, in his role of supervisor of works, when he has to attend works meetings?

-If company 2 should have operated earlier in the day, did it receive a new work permit?

These two questions raise the issue of the adequacy of the long, complex, centralized procedures for allocation of work permits and of the procedure for the coordination meeting (two essential steps to reorganize work after planning changes, as was the case in this accident) in the context of maintenance work characterized by time pressure, and the need for rapid responses to changes in local organization.

The question of the work permit delivery was not directly addressed at any point in the meetings. We have seen (see section 5.3.1.3.1) that C2 operates immediately when ACIO site needs it, if it is present. Moreover, the day of the accident, no change in schedule was notified for this operation. How could C2 have access to the site with a work permit issued yesterday for an earlier time? Did C2 operate frequently or usually without a work permit for this specific operation (pushing the STT)? Was C3 also required to work later (figure 21b)? Had its work permit been changed?

These questions lead us to raise the issue already tackled in chapter three, namely: the need for creating informal adjustments between subcontractors and ACIO operators. The complexity of the ACIO work organization, especially the allocation of work permits, does not seem to be consistent with the reality of work that requires adaptation to rapid changes, production constraints and time pressures. Thus, failures of coordination between contractors and ACIO operators, which seem to result in the construction of informal practices, may violate safety. This is not negligence or willful violation of the rule, but the result of a need to adapt formal rules to organizational constraints (reality and the context of work).

The company analysis and proposed recommendations seem to focus on compliance, or the creation of more procedures. The fault tree analysis does not question the very principles of management of subcontractors in a context of strong coactivity. It would have been interesting, we believe, to question the following points:

-The match between the process of the coordination meeting and the demanding requirements of planned works,

-The effectiveness of the system for allocating work permits.

Why did these two aspects we refer to as fundamental in the accident sequence, not get included in the formal records of the analysis of the accident and the lessons learned as captured in the Rex form?

5.3.1.4.2 Risk perception

In addition, the moving operation of the STT by the bulldozer was regarded as a benign action, which would not require a planning change and a new risk analysis beforehand. The circumstances of the accident showed that, in this context of work and high coactivity, this habitual operation could have caused the death of an operator of a subcontractor. The risk of pushing the STT with the bulldozer seemed to be seriously underestimated.

The issue of locking-off was also raised several times. If mechanical locking, added to the electrical locking, which was all that was used up to the accident, is now deemed to be necessary to avoid recurrence of this accident, we can assume that the risks were previously poorly assessed or under-estimated. Moreover, since the lookout played a central role on this day, despite being there for other specific risks, this indicates the fact that, for the job of maintenance on the STT electrical stations, no specific safety barrier related to the crushing risk from the STT movement was planned. Whatever the positioning of the STT, the risk of crushing could or should have been envisaged in the risk analysis. Why was this risk not foreseen in that risk analysis?

5.3.1.4.3 Information filtered out

We observed three limitations to the company's method of analysis of the event. The first relates to the approach itself. This appeared to be used quite formally, that is to say more to meet a requirement derived formally from legal requirements, than for the content of the analysis and its depth in relation to the event in question. The strong formalization of the event analysis (see section 2.3.1.2.1) is the first limitation identified.

The second one relates to the cognitive limitations of those responsible for setting up and executing the event analysis. The organizational factors (which we raised in connection with the accident) appeared to be too far from the technical and regulatory (compliance) context, and introduced too much complexity in the accident sequence to be taken fully into account and dealt with in the recommendations.

The third limitation concerns the political "limits". There was a reluctance to raise and share in documents transmitting information on an accident (the Rex notice is shared with other ACIO sites), the delicate questions of coordination, its failures and the informal practices that they have created. The issue of filtering information will be discussed further, in section 5.4.1.1.3.

The following section deals with incident 2.

5.3.2 Incident 2: accident on an oxygen pipe

5.3.2.1 Technical context and accident circumstances

Incident 2 occurred on an oxygen line. To achieve the steel conversion, the site is supplied by pipeline with pure oxygen delivered by Oxyair.

The site has three lines of oxygen (one for each converter) that conduct oxygen to the steelworks department that undertakes the conversion operations. The oxygen delivered through the line (figure 23) is an oxidant which promotes the burning of the carbon etc. out of the steel. However, with a high flow rate it may cause overheating and in contact with a flammable object (a mass of dust for example) can cause an explosion and start a fire. The oxygen sent by Oxyair is filtered to obtain a 100% pure fluid. The oxygen line has two filters (one line filter and a filter in a by-pass position in the event of temporary blockage of the line filter). Each filter contains 18 filter cartridges.

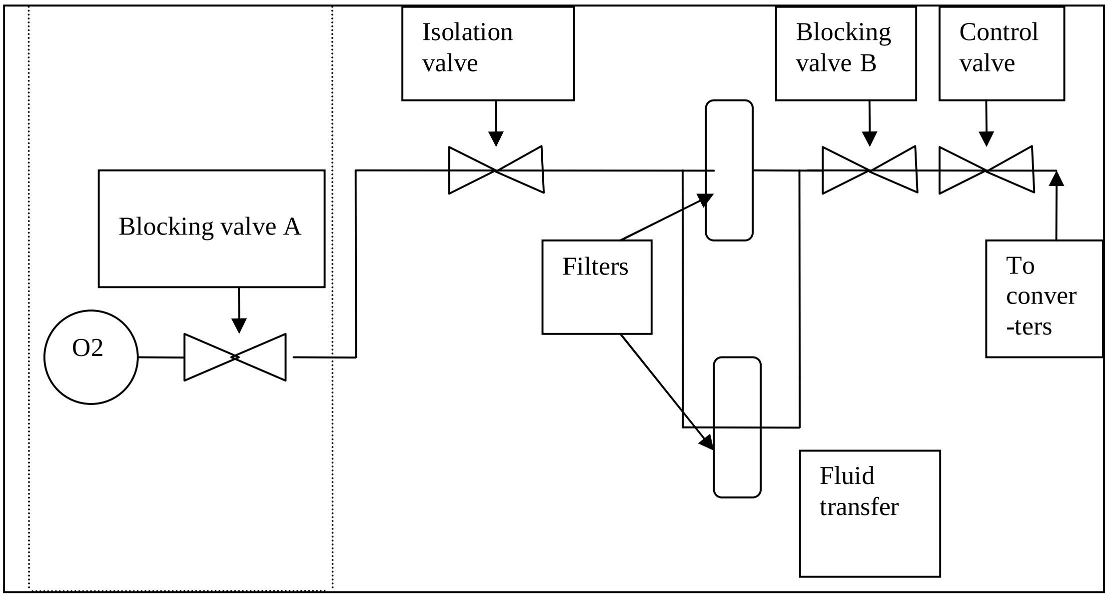

Figure 23: Oxygen line, ACIO.

Legend: the dotted part, called the 'sectioning post' is situated a considerable distance upstream of the rest of the oxygen line. The blocking valve involved in the accident is the one at the sectioning post A.

Oxygen comes along the lines with a pressure of 30 bars. However, the convertor requires oxygen at a pressure of 16 bars. The oxygen lines therefore serve to reduce the pressure of oxygen through the control valve which is located after the filters (appendix 12).

The line has three types of valves: the blocking valves, isolation valve and control valve:

> *"In this pressure reduction line, each valve has a specific role. These are the isolation valve, blocking valve and control valve. They are used at specific times. The valves are designed to fit their functions: the control valve responds at high speeds, it is designed to withstand very high speeds, they are manufactured only in stainless steel and bronze, there is no iron scrap used in making it. Control valves are there to regulate the flow rate and pressure. The blocking valve is also resistant to high speeds"*
> *"What speed approximately?"*
> *"It goes very fast ... 100 meters per second ... especially at the end. The blocking valve has to be closed at certain times and, like the others, which it is made of stainless steel and bronze. The isolation valve only closes if the flow is zero. It doesn't have a middle position, it is either open or closed and it is not capable of resisting over speed " (Technician, Energy Department)*

As shown in figure 23, the isolation valve is located upstream of the filters that caught fire on the day of the accident. It can be controlled in two ways: from a remote control post near the line or manually. The isolation valve is located 25 meters from the filter, protected by a concrete wall. This serves to protect personnel and the plant in case of an accident.

Ten days before the incident (D-10), a maintenance operation had been performed by a subcontractor on the oxygen line, consisting of replacing 18 cartridges in the line filter (the filter cartridges in the bypass position were just cleaned and replaced). The line was only put back into service four hours before the incident.

At 22.00 an operator of the Energy department in the control room noted an abnormal level of pressure (10 bars instead of 16 bars). To understand the origin of this anomaly, he went out onto the plant, accompanied by two other operators. One of the operators observed:

> *"When we went out to the line, there was a phenomenal noise, a wrenching of material, the filter had collapsed and the pipe was collapsing, but there were no flames. I got there after five minutes, but there were no longer any flames, just a noise ... like a jet engine, or similar. And on the wall we could see that the oxygen had sprayed out "(Operator)*

On the elbow of the line (figure 24), the filter had been gutted due to the fire and the control valve (safety valve) had melted behind the filter due to the fire and was no longer achieving its function of regulating the oxygen pressure (which explains the anomalous pressure decrease on the monitor screen in the control room). Because they were unable to operate the control/safety valve, the two operators decided to close the isolation valve manually upstream of the filter to stop the release of oxygen. We shall see later that manipulating the isolation valve carries a risk of over-speed and overpressure, which may cause a new outbreak of fire (as the oxygen sprays out faster as the aperture decreases as the valve is closing).

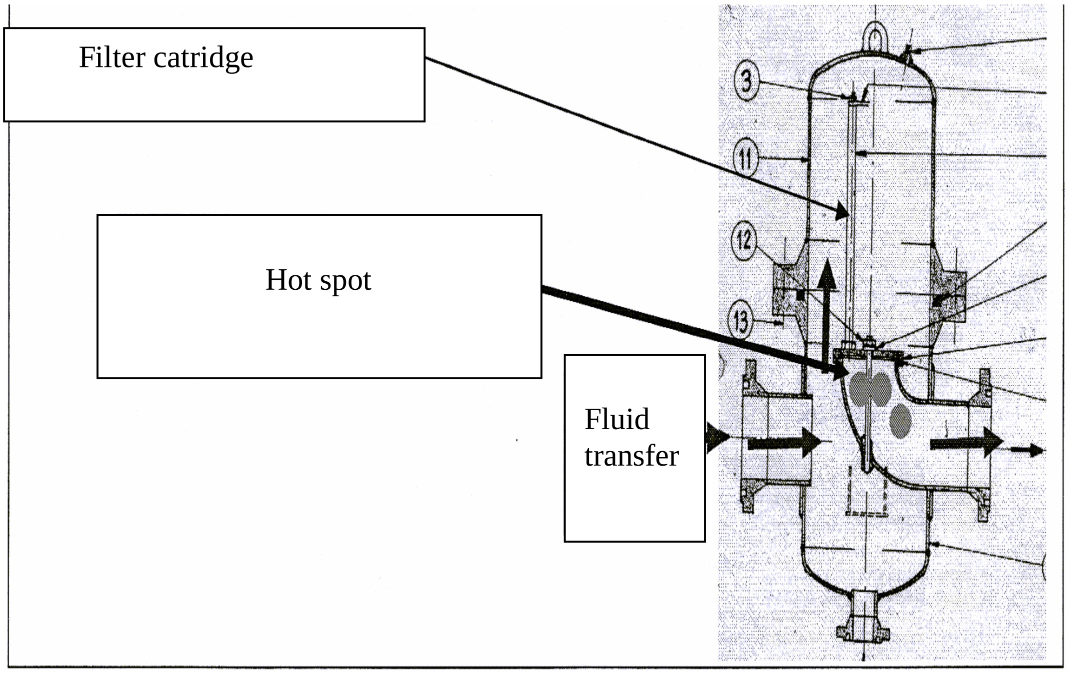

Figure 24: Oxygen line filter (picture taken from Rex form), ACIO.

The incident remained limited to a fire starting at the filter of the oxygen line. The filter and control valve melted and some material was ejected (pieces of metal), and a grill was destroyed. The operators' intervention helped stop the leakage of oxygen.

5.3.2.2 Event analysis: causes identified by the ACIO site

5.3.2.2.1. Official analysis: technical causes

The ACIO site conducted an in-depth analysis of the event. Internally an incident analysis was performed by the operations and maintenance services of the Energy Department. It was presented to a special Health and Safety Committee (HSC) meeting 24 days after the incident, and a Rex notice (Appendix 12) was constructed and shared with other ACIO sites. Externally, the company Oxyair (suppliers of the oxygen) conducted a technical analysis of the incident. The results and recommendations from this analysis were retained as the probable causes of the accident.

According to the analysis made by Oxyair: *"One or more broken cartridges created a bypass (increasing the passage of oxygen) resulting in over-speed at the elbow or the filter stem. A (dust) particle could have created a hot spot and in contact with pure oxygen arriving at an elevated rate, could have caused an explosion and fire"* (Extract taken from the expert report of Oxyair).

The incident was caused by a combination of pure oxygen and the presence of dust (due to poor quality filtering). This combination would have produced heating and then the start of a fire.

Thanks to the internal analysis and the Oxyair report, we learned that the filter cartridges were undersized and could not cope with the increased flow generated by an earlier intensification of the convertor performance and therefore of the oxygen delivery.

This was a latent technical failure unidentified before the accident.

5.3.2.2.2. Maintenance

The expert analysis provided by Oxyair and the analysis conducted by the Energy Department indicated technical anomalies upstream of the incident: *"It was reported that for some time during maintenance, filter cartridges had often been found to be broken in their bottom half. It was verified that this always occurs on the line filters and not on the by-pass filters. The entire batch has sometimes been found broken" (Extract taken from the expert report of Oxyair).*

"Note: When replacing previous filters, many broken cartridges have been found (Taken from the analysis conducted by the Energy Department and presented to the HSC).

Repeated anomalies on the cartridges of one of the two filters was identified following this incident. In addition, the Oxyair report stated that the support plate of the cartridges had never been removed, which would have prevented the detection of the anomalies. The second cause of the incident identified by the expert report was *"A whole range of incomplete maintenance or monitoring* ". Were these defects not communicated? Why, when they were detected, were they not taken into account in the system of technical anomalies management?

5.3.2.2.3. Organizational causes

Interviews conducted with two operators and the technical expert of the Energy Department provided further insight into the incident:

"On the wall we saw that the oxygen had sprayed out. The wall protection is like a bunker between the manual isolation valve and the filter, at a distance of approximately ... 25m. We had to isolate the flow of fluid. So I had two options: to close remotely by radio; the controller could have closed the remote blocking valve (A) to close the flow and lower the pressure. So I called the controller and said "get ready to close. But I still wanted to know if I could close the isolation valve manually. The pressure was so strong that I could not close it but we tried again and we could. So we did. If we had closed the (remote) blocking valve that would have taken too long, we would have had to wait 5 hours to remove all the fluid from the line, while here we could shut it and within minutes it was over" (Operator)

"In fact there was no conversation between us, we are accustomed to working together, often there are no words. Here, because of the noise it was difficult to hear. We were 3, we tried to turn the valve and it closed ... (short pause)" (Team leader)

The operators originally intended to operate the automatic safety valve (control valve) next to the filter. Noting that it had melted, they had two options: closing the remote blocking valve (valve A in figure 23) that would have shut off all of the oxygen to all converters, which meant stopping steelworks activity for several hours (thus a production loss), or manipulating the isolation valve on the single line to stop the leak of oxygen and prevent a new outbreak of fire. The operators chose the second option.

However, as we have seen the isolation valve should only be manipulated with zero flow. According to the technical expert, the operators should have operated the blocking valve:

> *"During the incident, a fire started in the filter and the operators closed the isolation valve".*
> *"Because they thought to reduce the flow of oxygen and therefore reduce the fire?"*
> *"Right .. They closed the valve and then stopped the flow. For me the problem is what was done after, not the fire which started. What they ought to have done is to activate the blocking valve (A) by calling the controller or by pressing the emergency stop. Because by closing the isolation valve they risked over-speed, whereas by activating the blocking valve, it would have been properly isolated. For me, the real incident took place after. They were lucky nothing happened" (Technician, Energy Department)*

Closing the isolation valve sharply could have increased the flow speed and pressure of oxygen and blown up the pipe. The consequences of such an explosion for the operators could have been significant (wounds and burns).

The technical expert raised a new aspect of this incident, the underestimation of risk. First, the intervention used by the operators could have aggravated the initial incident. Second, intervening very close to the (fire) incident carried the risks of burns, or ejected materials. Both risks were poorly assessed by the two operators (worsening of the incident and impact on personnel), which could reveal, according to the technical expert, a lack of knowledge about the risks that pure oxygen can cause:

> *"The problem is when you work based on habit, that... becomes dangerous. The guys are not aware of the risks. There were just two of us who know, the supervisor who retired a year ago, and me. Now the guys don't know the risk of oxygen, so now (...) now the guys they have no knowledge of this plant, so when there is a problem, they don't know what to do. They closed the isolation valve like they would have closed the water tap, it looks the same ... when you have no knowledge .. " (Expert,Energy Department)*

The reasons why the operators took this risk are, according to our point of view, more complex. We will try to explain the main features below, section 5.3.2.3.2.

5.3.2.2.4 Actions

The actions recommended by Oxyair enable us to treat the causes of the incident identified at several levels.

First, the Oxyair report recommends technical measures related to the filtering system. It advises a resizing of the cartridges so that they can withstand the new conditions of service. The Rex noticespecifies that the number of cartridges should be increased from 18 to 28, and the filtering system should have only one filter (and not two any more). These changes aim to develop a filtering system which is more robust and reliable and able to cope with the new conditions of production.

Next, the Oxyair report recommends to "*check the marking of, and conditions of access to the danger zone*" (the oxygen line). The Energy Department did in fact review the procedure for accessing this area:

“Each line has been modified, now there are bunkers around, you cannot get in during normal operation” *“And if something goes wrong?”* *“They must isolate the line, which unlocks the doors, and they can get in. Ah, it's quite a paraphernalia now. In fact bits of the filter were ripped off, we’re still not sure why ... It's protected now, but we passed hundreds of times near the line without knowing the danger ..." (Energy Department technician)* *"Now everything has changed: we have to isolate the line and open the vents to intervene. It takes 1 hour when previously it took 30 min. So now we isolate upstream and downstream, the vents are opened to drop the pressure. It’s all procedures. When the lines are decompressed and the pressure is zero it unlocks the key mechanisms. Then you can enter the bunker with the key" (Energy Department operator)*

The incident led to a revision of access to the control cabin[39] for the oxygen line but also to strengthen the protection devices of the line. Before the incident, the oxygen line was easily accessible. Operators could access the control cabin during normal operation (when the line is in operation) by opening the doors with a key. In addition, the area of the oxygen line was only bounded by a metal grille and no concrete structure protected the area surrounding the plant. Now, before access to the line, it must be isolated (that is to say, emptied of its fluid) and depressurized (0 bar pressure) by using the blocking and isolation valves. The isolation and depressurization of the line unblocks the access doors to the line. Once unlocked, the doors can be opened, and operators can access the control cabin. Also the oxygen line is now surrounded by a concrete structure which completely isolates it from the exterior. These new measures have two objectives: to protect the environment of the facility in case of explosion or fire, and to protect personnel working on the installation.

Finally, the analysis of accident 2 performed by ACIO drew three lessons.

-Technical change: change the filter system,

-Procedure change: access to the oxygen line,

-Knowledge change: training on the risks of oxygen.

However, some issues remained unresolved.

5.3.2.3 Identification of weak signals

This section aims to explore the limits of the event analysis conducted by the ACIO site, and to identify two weak signals of the accident not included in the Rex form.

[39] The control cabin is located a few meters from the line A in which operators can operate the isolation and control valves.

5.3.2.3.1 A latent technical failure

First, the repetition in the past of defects on the cartridges was identified twice: in Oxyair's report and in the analysis conducted by the Energy Department. We hypothesize a latent error in Reason’s terms (2000)[40] (see section 2.2.2.3), that is to say, a persistent technical fault because of an ineffective maintenance procedure. Accident 2 revealed and examined that latent error.

Although it is mentioned in Oxyair report, the problem of filter maintenance was only partly treated. Indeed, the report advises a change of the filter system and not a review or an analysis of the maintenance procedure (frequency of the anomalies, monitoring of operations etc.). The accident could have led to the review of maintenance plans but also of the technical anomalies reporting system.

5.3.2.3.2 Risk perception

First of all, for the operators, the manipulation of the isolation valve was perceived as a rapid solution to the problem the operators were facing and avoided stopping converter operations for a long period (thus avoiding production loss). However, the HSC report and the interviews showed that the operators’ action involved a significant risk. They could have aggravated the initial incident and been themselves severely injured. That raised the issue of the knowledge and risk perception of the operators. However, as Reason (op. cit) showed, such a decision can be influenced by an organizational context that favors such action: inadequate knowledge or training of operators, ambiguous procedures or rules, practices contrary to safety accepted by management. Our hypothesis is the following: the operators’ decision-making, to close the isolation valve, cannot be reduced just to a willingness to brave a risk but reveals the need to balance a second requirement, that of completing the task within the reality of a context which favors production.

Then, the incident on the oxygen line could have led to a questioning of the decisions of the operators. On the one hand, why did these operators focus on maintaining the converter activity to the detriment of their own safety and that of the installation? On the other hand, what actions could the ACIO site put in place to avoid in the future that the operators prefer the objective of production at the expense of safety? Implicitly this last point may have been achieved by interlocking the access to the line and its isolation valves with a shutdown of production, but that solves the problem only for this part of the plant in this eventuality and does not identify it as a generic problem to be tackled elsewhere.

Finally, data on the risk analysis of the oxygen line are lacking, but we can advance the following hypothesis. After this incident, the physical (protection wall) and organizational safety barriers (the procedure for access to the line) required major revisions. The initial risk analysis

[40] Reason J., (2000), Human error, models and management, in BMJ, vol. 320, pp 768-770.

could therefore not have taken into account the incident 2 scenario (in respect of both the causes and consequences of the event) and therefore underestimated the risks of pure oxygen.

In conclusion, this case helped us to formulate the following idea. Despite the analysis of the event set up following the incident, our own analysis of Rex process has led us to the identification of two weak signals which were ignored: the persistence of latent technical defects and an underestimation of the risk of oxygen (combined with placing a priority on maintaining production and not safety).

We turn now to the third and final case.

5.3.3 Accident 3: silo explosion

The third accident case has several points of interest. First, the chronology of the accident highlights the emergence, a few days before the accident, of warning signs only interpreted as such after the event. Second, as in cases 1 and 2, the ACIO site conducted an in-depth analysis[41] of the event which resulted in the design of a new silo and the implementation of measures to improve safety barriers, but which we were also able to examine critically for any failure to pick up weak signals.

The next section presents the technical context of the accident. Then we will return to a detailed chronology of the three days preceding the accident, during which technical anomalies were observed but not interpreted as accidents precursors. Finally, we will discuss the Rex process conducted by the ACIO site, focusing on the lessons that were learned from this event and issues which, from our point of view, remained unresolved.

5.3.3.1 Technical context

Alpha[42] product is stored in a silo with a volume of 230 m³ built some twenty years ago. It is located a hundred meters away from the desulfurization unit to avoid storing too much product in the facility. In contact with water, Alpha forms Gamma, a flammable gas.

Alpha is transported from the desulphurization silo through a sieve by two pneumatic lines, (alpha is a powder) and is stored in two tanks called "feed hoppers" containing about 20 tones of product each. The transfer of Alpha from the hoppers into wagons, to be moved to the desulfurization operation (injection of Alpha into the smelter), is controlled by an operator in a cabin. He also monitors the safety measures such as the concentration of Gamma in air.

[41] According to ACIO requirements.

[42] The names of the different chemicals are made anonymous to maintain confidentiality.

Dry air (not pure oxygen), sent by Oxyair is injected through nozzles located in the bottom of the silo to fluidize the product (a valve located at the roof of the silo allows depressurization). Although Oxyair sends dry air, it is filtered to avoid any presence of moisture and therefore risk of forming Gamma. Controls for gamma are regularly conducted. The air in the silo, is sampled by a sensor on the roof and sent by a pneumatic line, to an analyzer located 100 meters from the silo.

«We look at Gamma with what you might call archaic sampling methods. These are pumps which sample the product with pipes about 100m long which transport the product to analyzers. So, we never know if the pipes leak, there could be air in the product at any moment. This calls the whole system into doubt.».
"The analyzers are laboratories?"
"No, they are little analysis stations, little boxes. The silo is in an isolated area, so we cart the product over 100 meters"» (Steel works Employee)

This probe is made of porous material; every 15 seconds, it is unclogged, which is to say that air pressure by the action of a pump driven by nitrogen, clears any dust that has accumulated on the probe. If the analyzer shows that Gamma concentrations are too high, this means that moisture is present in the product. Fluidization and transport of Alpha will from that point be carried out with nitrogen, an inert gas, to avoid increasing the temperature of the product and thus the risk of ignition.

5.3.3.2 Accident circumstances

The interviews we conducted and documentation relating to accident 3 helped us to reconstruct the chronology of the accident as follows:

5.3.3.2.1 Day -3: high readings of Gamma

Three days before the accident, high levels of Gamma in the hoppers were observed by the operator in the control room:

«So three days before at 09.40 we noted some Gamma at hoppers 1, which was linked to some rain» (Major Hazards Employee)
«Three days before we had detection of Gamma at threshold levels 1 and 2. Level 1 was at 1500 ppm and level 2, 3000 ppm[43]» (Steel Works Employee)

But the operators had some doubts about these readings:

[43] Particles per million.

> *«During this process the operators had some alarms indicating the presence of Gamma. But isolated traces of Gamma like that have occurred several times over several days or even months. So that didn't alarm them, it had already happened. But, according to me that should have alarmed them. But there weren't any other alarms, so they could say «perhaps there is a failure of the alarm … » (…) So, it's true that, in this case there were precursors which were hard to interpret».*
> *« Why? Hadn't there actually been readings of Gamma several days before?"*
> *« Yes, but there had been lots before in isolated ways. There had also been some heating, which was worrying; but it is easy to say that with hindsight. Today I think we would react immediately. I spoke to Stephen about it again recently and he said to me "but we didn't know what to do"." (Major Hazards Employee)*
> *«So what happened? …Two or three days before we had readings of Gamma. We didn't understand where the Gamma was coming from, because the air readings were giving 0 humidity. So we thought that there was no humidity in the silo because of the monitoring of the air. So, for us, there were no problems on that side. So we queried those readings » (Maintenance Employee Steel Works)*

Several employees therefore preferred to believe the hypothesis of a failure of the measurement system for Gamma. Their confidence in this belief prevented them from perceiving the risk and more accurately interpreting these anomalies as precursors of an accident. So, the desulfurization process stayed in operation.

5.3.3.2.2 Day -2: control probe for measuring Gamma levels

Two days before the accident, a defect on the sensor level control product was detected. The operator in the desulfurization control room communicated this anomaly which triggered a request to intervene. A maintenance team intervened, but failed to solve the problem.

On this occasion, the team of operators (our data doesn't indicate if they were operators or maintenance) identified two new anomalies. The first was a problem of the unclogging (see section 5.3.3.1) of the Gamma probe. Maintenance crew then decided to check the flow and the filter made of porous material. The second anomaly was a leak discovered in the unclogging pump:

> *«In order to drive the unclogging pump we use nitrogen. The probe had a leak and we realized we were not sampling the gas but the nitrogen…. So we were following the unclogging procedure, you could say that everything was OK with that procedure, but in fact we were sampling nitrogen… »*
> *« So, OK… you had a procedure saying all was OK, but…".*
> *"That's right. In fact every month we have to check that the pump is good: the pressure, the flow, etc. No problem had been detected on the pump and we had 0 on the Gamma, so we were certain… And comparing the two detection systems, on of the two was surprisingly dead… » (Steel Works Operations Employee)*

So, the maintenance crew detected a leak of nitrogen from the unclogging pump. The Gamma probe was not sampling the silo air but the nitrogen from the unclogging pump. This explained the zero values of Gamma indicated by the probe.

The second defect was a high temperature reading on the silo roof (where there are also probes). The detailed chronology prepared by ExperIndustrie indicates: "*The floor of the silo was not cold,* *it was warm (10 or 20 °C). This did not worry them, though with hindsight it should have done. Some say it was common, others not".* (Excerpt from an interview with ExperIndustrie).

The operator did not transmit this information at the shift changeover.

5.3.3.2.3 Day -1and day 0: high temperature, high levels of Gamma and silo warm temperature

The day before the accident, the unclogging pump was repaired. A few hours later, readings of Gamma – threshold levels 1 and 2 - on the silo were observed as well as a high temperature of the silo floor (which usually should not be the case):

> *« So the first step was the detection of Gamma, but the day before the silo exploded there was warmth, but there was no reading of Gamma any more, while the reaction was already on-going"*
> *"You had had high levels of Gamma?"*
> *"Yes, but there was no water, we saw nothing, no cracks. We just knew there was rain, it was in December, but had not made the connection" (between the rain and the high levels of Gamma - addition of the author) (Steel Works Department, Maintenance Operator)*

Despite these anomalies (high temperature, high levels of Gamma), an impending accident was not considered.

Two hours before the accident, the desulfurization unit manager detected an abnormal temperature of the silo floor. He checked this with his hand, and felt that there was indeed abnormal heat at floor level and in the Alpha transfer sieve. The unit operator found also a problem with the flow of Alpha. The first explosion, followed by a second one about 30 seconds later, caused part of the roof to blow off and ripped opened the silo. The silo was therefore unusable. The design and construction of a new silo were therefore necessary.

5.3.3.2.4 Accident consequences

Firstly, fire-fighters arrived at the site of the accident two minutes after the accident to set up a safety cordon. 45 minutes after the event the emergency Internal Operation Plan (IOP) was triggered, but then lifted at the end of the afternoon:

> *"Firemen and people from Energy department arrived at 6:59 am. They triggered the IOP. This alerts the trio needed for the IOP: the fire service, the Energy department and the operational department where the accident has occurred "(Major accident service)*

Monitoring of the temperature by thermography was performed for four days. During the five weeks following the accident (Day +35), checks for fire were conducted twice per shift (that is to say, every eight hours) and neutralization with inert gas was maintained.

Then, to proceed with the replacement of the silo, ACIO first started to empty it, as it still contained the reactive product:

> *"So what did I do? I cut the silo, without creating any sparks, using a mechanical saw, and I made a lid to cover the rest of the silo in case of rain (...). And then we said "we'll smash it up" to remove the hardened pieces of Alpha. But we tried and nothing happened. So I waited for good weather, it was a long time coming: it was in July, seven months after the accident, and we hauled out the product with a large bucket clamp (...) The clamp filled the Big Bags" (Employee Design and New Projects)*

To do so, the Design and New Projects Department conducted an operation which involved the cutting open of the silo and its subsequent emptying using dumpsters, armed with grabs, which extracted the product through the opening. Part of the Alpha had turned solid, but another part was still usable. Big-Bags (whose capacity can reach 500 kg) were therefore filled and used in the desulphurization.

Once they had made a reconstruction of the chronology of the accident, ACIO analyzed the event whose main results we present in the next section.

5.3.3.3 Event analysis

Accident 3 was analyzed in detail by ACIO:

- -Analysis conducted by the Steel Works Department,
- -Rex process,
- -Health and Safety Committee,
- -Expert analysis conducted by an external company: ExperIndustrie.

These documents and the interviews we carried out revealed two types of root causes: technical factors and causes related to the maintenance and design of the silo.

5.3.3.3.1 Technical causes

First, the ExperIndustrie report showed the occurrence of two reactions. The first was the infiltration of water through the roof of the silo three days before the accident, which generated the formation of Gamma (a potential reaction known to the site and the expert). We have seen that the desulfurization unit did not perceive the high levels of Gamma and of temperature as accident precursors. The unit maintained the normal operation of the silo, and more specifically, the fluidizing and transporting of Alpha with dry air. However, the reaction with water increased the temperature, which reached about 200°C, and generated Gamma gas undetected. Alpha, when heated above 200°C reacts with air (injected into the silo to fluidize the Alpha) and forms another explosive gas, Beta

Not knowing of the first reaction, the desulfurization unit contributed, unwittingly, to the second reaction by maintaining the dry air fluidization. The latter was more significant because it had been increased to facilitate the Alpha transfer (following the detection of an abnormality in the transfer of the product, see section 5.3.3.2.3):

> *"Together with ExperIndustrie, we learned that from 200 degrees, a second reaction is set off. There had been a rise in temperature without us realizing it in a second time. So the product reacted with oxygen. In fact Alpha reacts with water and with oxygen at a certain temperature. Alpha is also a good insulator so it was very hot in some places without anyone noticing (...)"*
> *"And ExperIndustrie did not know of the reaction either?"*
> *"No, they also discovered it at the same time as we did. They did some tests at their premises. In the end, they knew of the reaction but had no idea it could happen on an installation of Alpha. What happened is that we also made it into an exothermic reaction, that is to say, when we blew air through the nozzles because anyway we had no high levels of Gamma. We self fueled the second reaction by blowing the air though it. It was like a barbecue: it initiated the reaction and consumed Alpha. So we increased the temperature " (Steel Works Department, Maintenance Manager)*

5.3.3.3.2 Deeper causes: silo maintenance and design

Next, the Expertindustry analysis raised a deeper cause of accident 3. It observed advanced corrosion in the silo roof. Part of it had become inaccessible to operations and maintenance monitoring. The anticorrosion painting had therefore not been performed. Moreover, this inaccessible part was invaded by seagulls whose corrosive droppings accelerated the process of roof corrosion. In addition, the roof of the silo was not completely closed. It was a temporary structure which was intended to be replaced by a definitive structure. These three elements made us understand the reason why water seeped into the silo.

Accident 3 differs from the other two. The circumstances were a surprise since the second reaction was unknown to the ACIO site and also to the external expert.

5.3.3.3.3 Technical lessons drawn from accident 3

After the accident, ExperIndustrie proposed several recommendations which have all been followed in designing the new silo.

First, the roof of the silo was designed to prevent water infiltration. It now has an extra collar and a stainless steel cover. Previously, the roof was a steel shed roof, covered with an anti-oxidizing paint which was specifically inadequate. The roof is now accessible via an external access and monitoring of corrosion is carried out, while a gutter allows rainwater to flow along the walls of the silo and not seep inside it.

Next, the new silo is equipped with temperature sensors at various points (to monitor a possible formation of beta) and sensors for oxygen (which is no longer necessary for fluidization) and a more accurate detection of Gamma. To avoid the transport of air to be analyzed along a 100m line, which may itself contain moisture, Gamma is now measured with a diode laser directly in the bin

Finally, fluidization and transport of the product are not carried out with oxygen but with nitrogen. Argon gas serves as the backup fluid.

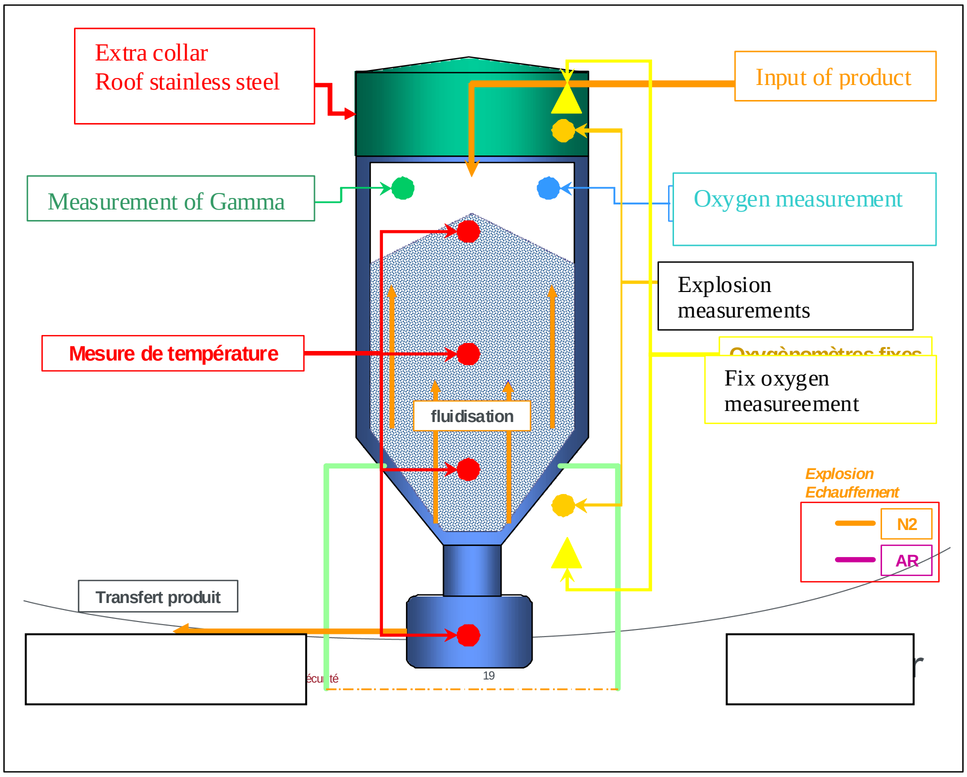

Figure 25: Design of the new silo (Source: ACIO).

Why were these new measures not taken into account when the first silo was designed?

Moreover, after the accident people working nearby the desulfurization unit were trained on the danger of Alpha:

> *"After the incident we trained people on the risks of Alpha. (He shows me the DVD training. Two tests were conducted, first a flame was thrown onto some Alpha which produces no reaction, then water is poured on the product which forms Gamma and hence bursts into flames)."*
> *"They were trainers from Eastern Europe?"*
> *"The training providers were German but the video was in fact made by suppliers in Slovenia and Slovakia. I realized we should have this sort of training regularly because operators have lost knowledge ... and it is important for precursors of accidents"*
> *"And this training was only made for the steel works operators?"*
> *"It was made for personnel working near the silo and desulfurization area" (Steel works department, manager)*

Also a benchmarking visit to a foreign factory helped ACIO employees to update their knowledge on the product:

"In fact, we did a benchmark in Slovenia and we saw that they did not use any oxygen but nitrogen. When we told them we used the oxygen they raised their eyebrows.. " (Employee steelworks)

Finally, the risk analysis of the silo was revised and modified (appendix 13). Overall, air (or oxygen) was replaced by nitrogen (N_2). The back-up gas is no longer nitrogen, but argon. Then, for the dangerous situation defined as "Entry of moisture" the preventive measure put in place was monitoring of oxygen (an instrument included in the new silo), temperature and Gamma. Finally, if self-ignition is detected, the steel works department replaces nitrogen by argon.

Accident 3 was thus an opportunity to review the design of the silo with new knowledge on the reactions of Alpha. Lessons learnt were mainly technical and related to: the systems for measuring levels of Gamma in the air, oxygen and temperature and the fluidizing gas.

Improvements	**Lessons learnt**	**Old silo**	**New silo**
Silo design	Water infiltration	Known risk but underestimated	Closed roof in stainless steel
Technology related to product	Alpha and water	In contact with water, Alpha forms Gamma an explosive gas No knowledge of the second reaction	In contact with water, Alpha forms Gamma an explosive gas No oxygen so second reaction not possible
	Alpha and air increase temperature of the product		Gamma reacts with carbon when temperature is higher than 200°C
	Fluidization and transport gas	Dry air (filtered before injection) Nitrogen : backup gas	Nitrogen. Argon : backup gas
	Gamma levels	Measures of air in an analyzer situated 100 meters from silo. Pneumatic transport	Measures made by laser diode directly in the silo
	Oxygen levels	None	Two fixed instruments
	Temperature levels	Imprecise temperature measures	3 temperature measuring points with accurate readings

Table 3: Lessons learnt from accident 3, ACIO.

5.3.3.4 Toward identification of weak signals

Four factors seem to explain the gap, or ignorance of accident precursors: technical anomalies not believed by the operators, a blind confidence in their know-how, information scattered, and finally a latent technical failure identified but untreated.

5.3.3.4.1 Doubts about anomalies

First, interviews revealed that the high level of Gamma was not exceptional, it seemed even to be recurring. Other measures commonly used to confirm the presence of Gamma indicated that "everything was fine”. In this case, the measured humidity level was 0. However, the temperature measurement was imprecise, so it was difficult for operators on site to judge whether the temperature was exceptional or not. The measurement system itself was called into question - it could itself contain moisture - which led operators to maintain the desulfurization process in operation, without considering an imminent risk of accident. The head of the steel making department said:

> *«It would also have been possible for the shift operators who do visual inspection rounds to see what was happening … Ok, it was an exceptional event. We had indications three days earlier, of heating, but, OK, that was not clear» (Head of the steel making department)*
> *«The first signs were the continuing warning lights, but what they didn’t say was that there had been warning lights for three days. The department head arrived at the moment that it exploded, if the installation had been defined as high risk, it would have been an apparatus to be looked at closely. But the day shift guys don’t have time to do everything. They didn’t see the warnings as high priority or they didn’t have the overview to analyze them like that. Or it was the supervisor’s job to do that, but he didn’t have the information. The day shift guys have to tell the boss about it» (Head of the steel making department)*

We shall see later that the difficulty of this accident lay in the possibility of making sense of those anomalies.

These indicators can be defined as routine and mixed signals (according to Vaughan’s categorization, see section 2.4.1.2). They are routine signals because, according to several interviewees, high levels of Gamma were previously reported without any accident occurring. They are mixed because, although they indicated anomalies, audits conducted by operators showed that "everything was going well." It therefore seems particularly difficult, in this case, to judge these indicators as signals of an accident, due to the ambiguous characteristic of the anomalies detected.

5.3.3.4.2 Fragmented information

Secondly, the information source and nature played a role in the difficulty of interpreting these signals. The information held by the different actors was of different nature: technical indicators: high temperature and Gamma levels, physical or mechanical malfunctioning: the probe for the product level, the unclogging pump.

Next, this information was detected at different locations (and therefore different steps in the desulfurization process): post-desulfurization (hoppers), on the silo itself, the silo analyzers,

Finally, the operators had different expertise and positions: cabin operator, operator on the field, and maintenance operator.

Part of the difficulty of this accident lies in the dispersion of information of different nature held by actors with different positions in the organization. For these reasons, the integration of information and making sense of the technical signals were more difficult.

5.3.3.4.3 Risk perception: blind confidence?

The interviews carried out revealed a « blind confidence »:

> *"But your initial question challenged me "How to avoid accidents?" In fact it is habits. There were high levels of Gamma, hot spots, but nothing happened. We were overconfident. The warnings were lit up, there were subtle things that we did not want to see"*
> *"Like what?"*
> *"Well ... difficult to remember but ... It's like a car, the little noise you hear for a few days, it's nothing significant and we think that we will deal with the problem later, until the accident... In retrospect it's easy to say "yes I saw it" .... How to stay vigilant?" (Steel works department, employee)*

This attitude towards risk would have therefore prevented operators from linking the failures observed – the high level of Gamma in the hoppers and silo, the high temperature of the silo and a problem of unclogging the Gamma probe - which were in retrospect, clear indicators of an impending accident.

5.3.3.4.4 Silo maintenance: latent technical failure

We did not obtain any more information on the problem of maintenance of the silo. However, three questions may be raised:

-Had water seepage been detected before?

-How was that treated?

-Why did the site maintain a temporary facility in operation?

Maintenance facilities and particularly the identification of recurrent anomalies will be addressed in Part 5.4.

In conclusion, accident 3 generated essentially organizational single loop learning. It generated a better understanding of the reactions of the Alpha product, thereby modifying the risk analysis of the facility. The structure of the silo, measuring system for Gamma and the fluidizing gas were changed; measurements of temperature and Beta have been added. However, the Rex process conducted by the steel-making Department did not advance to an organizational double loop learning, in so far as the difficulty in perceiving the signs of an accident a few days before the accident was not questioned. It seems that incorrect risk perception, characterized by a difficulty to consider the worst case, blocked the possibility of receiving/accepting these signals of the impending accident.

5.3.4 Conclusion on the accident analysis

After each accident, the ACIO site put a Rex process in place, and identified the circumstances of the incident and the main accident causes and implemented actions to resolve problems raised. Our analysis led us to identify three aspects common across the three accidents, which were untreated in the Rex process:

-A latent maintenance failure,

-A failure of the management of coactivity,

-An inadequate risk assessment and design (the silo).

We argue that these three aspects are weak signals of accidents for several reasons. They are repetitive and known signals, they were not taken into account in the Rex process because the link between these signals and safety (or the role of these signals in the accident sequences) was neither clear nor direct. Their complex nature (as signals revealing organizational dysfunctions of safety) made them hard to discern.

The next part of this chapter will lead us to identify where and how these weak signals are rooted in normal operation.

5.4 Normal functioning: the roots of weak signals

The previous section discussed three cases of accidents that we have analyzed in terms of organizational learning. They allowed us to show the limits of the Rex process that result in difficulty in taking into account information from weak signals. We identified three of these signals:

-The persistence of a latent technical failure or technical weak signals,

-The persistence of a lack of coordination between subcontractors and ACIO employees,

-Underestimated risks.

Through observations and interviews, we identified three aspects of the normal functioning of the site whose analysis will help us understand the "sources" or the origins of the persistent weakness of signals. We will group discussion of them under three headings in two sections of this chapter:

1. **Maintenance management** and more particularly the **treatment of anomalies** detected on facilities are used to identify the sources of technical weak signals. Maintenance plans are used to prevent or correct technical deficiencies on equipment, but we need to look at three additional elements related to learning (in section 5.4.1.1):

-Do maintenance plans allow for the identification and analysis of the causes of recurrent anomalies detected?

-What is the "depth" of the changes made to equipment in technical and risk analysis terms?

-Further to the first two questions, to what extent does the ACIO site take a critical look at the effectiveness of maintenance plans? Are these reviewed?

2. An analysis of the **management of the coactivity of maintenance subcontractors** will make clear how deeply the weakness of work coordination is rooted. We will raise the following questions in section 5.4.1.2.

-To what extent are the tools/procedures developed by the ACIO site to coordinate subcontractors, particularly in the case of schedule changes, adapted to the context of the maintenance works in which they have to be applied?

-Are tools and procedures reviewed?

3. **Effectiveness of safety management tools** (dealt with in section 5.4.2). Two issues will be raised, to help us understand why and how signals relating to estimation of risk remain weak:

-What is the depth of the analyses conducted by the Rex process?

-Is the effectiveness of this tool reviewed?

Shortcomings in these three activities represent barriers to learning and, therefore, to taking account of weak signals. These blocks are in turn rooted in three organizational characteristics which will be dealt with in section 5.4.3:

-Organizational fragmentation, which is found in a compartmentalization at two levels: operation/maintenance, and contractors/ACIO personnel, which makes more complex the process of coordination and which promotes the use of informal strategies which may conflict with safety.

-A closed communication system which leads on the one hand to a mechanism filtering out information which does not fit with the analysis frameworks used and, on the other hand, to a fragmentation of databases (particularly between the technical [maintenance] data and data related to safety) and thus a difficulty in integrating and processing information.

-Finally, the event analyses put in place following an accident generate organizational single loop learning, which does not allow for the uncovering of the deeper root causes of recurrent events or for questioning and revision of the basic principles underlying the management approaches used.

The next sections are devoted to the description of the three activities of normal operation that are at the root of the persistence of the weakness of accident signals.

5.4.1 Maintenance management: planning and coordination

Normal operations mean all activities that maintain the operation of the site outside of any accident situations. It covers observations focused on the daily work of operators and managers and more particularly on the tools and methods at their disposal to ensure safety during maintenance works.

The next section discusses how anomalies are reported, maintenance is planned and the Prevention Plan is developed to fulfil its function of coordination and of securing the safety of personnel and facilities during the completion of maintenance work.

5.4.1.1 Technical anomalies reporting

5.4.1.1.1. Detection and diagnosis of technical anomalies: Energy department

An anomaly is defined as "*A malfunction, fault or failure. It is always defined relative to a standard state. It may be detected by any personnel*" (Source: Energy Department internal documentation). When we were conducting the ACIO case study, the Energy Department had just put in place a computerized system for the detection and treatment of technical anomalies (equivalent to SAP on the EDIA site).

A technical failure can be detected and communicated in two ways; either by any operator (ACIO or subcontractor) working on the site, or during a site inspection round carried out by a team of operators. The anomaly is then "diagnosed". It can be addressed immediately, that is to say that the operator finds a solution without asking the maintenance team to intervene, in which case it will be labelled with a blue tag, or it will need an intervention because the operation is too long or too complex to be resolved in the field, which will be indicated by a red label and will be the subject of a request to the maintenance department.

The anomalies are then processed in an operations meeting[44], every morning at 8:15. Together the manager of operations and the operators assign priority to the anomalies: priority 1 means that the anomaly must be resolved the same day; priority 2 within a week and priority 3 within a month. This labelling procedure is a requirement of the Total Productive Maintenance (TPM) system, and is applied in all operational departments.

44 The Energy Department is comprised firstly of an operations department, which has five teams of operators, whose tasks include monitoring of the facilities for which the department is responsible (such monitoring takes the form of regular field inspection rounds carried out by a team of at least three operators) and monitoring of anomalies in the control room. Two operators of the department are constantly present in this control room. They monitor on screens the flow of energy that is distributed throughout the plant and also identify and address any deviations found on the screens. The Energy Department also has a maintenance department, which is responsible for coordinating the daily work and large construction projects (the outages), and managing contracts with subcontractors. Maintenance technicians have two management roles: to record requests for action following the detection of a technical fault and to organize the operation with the subcontractors selected for the realization of the intervention.

Anomalies are therefore treated according to a severity scale (1, 2 and 3). It defines maintenance work according to priorities in time (short, medium and long term) and triggers a corresponding level of appropriate organization: priority 1 anomalies will be largely curative and "simple", priority 3 are largely preventive and "complex” (we return in detail to this point in section 5.4.1.1.3).

5.4.1.1.2 Anomaly treatment: contractor’s management

“Red” anomalies are transmitted through the Maxigès management software, designed for treating technical failures and are turned into “intervention requests” which are taken up by the maintenance operators (ACIO employees). The latter create a “work order” and send it to the subcontractor responsible for performing the maintenance work. The work order (WO) includes a description of the procedure to be performed but also automatically includes a Workplace Safety Instruction (WSI). This form, already pre-designed in Maxigès, reminds the fitters of the risks inherent in the operation and the control measures to ensure personnel and plant safety. There is a Workplace Safety Instruction for each operation. Once the work order has been raised the (ACIO) maintenance operators are responsible for creating a Prevention Plan with the subcontractor and checking the site where the operation has to be performed. There are two types of Prevention Plans (or PP): an annual prevention plan and a specific prevention plan. The first is signed with subcontractors involved regularly on the ACIO site. This PP, revised every three months, already contains the safety studies made by the subcontracting company. When that company comes to do any work, their PP is applied and separate safety studies are not required. The work permit is granted automatically and quickly. The specific PP is developed for the realization of work in coactivity. The process is much longer and more complex because the risk analysis due to the coactivity has to be revised or redone. In both cases it is the subcontractor who must submit a risk analysis and a work procedure for his intervention.

When the work order has been validated and registered in Maxigès, it is automatically sent by email to the production unit operators. They take into account the work orders issued in Maxigès software and have two main functions. First, they are responsible for isolating and making safe the installation on which the work will be performed and, once is the work is done, the checking and restarting of the installation:

Example: isolation of plant before any maintenance on a water treatment plant (Energy Department):

The process water and rainwater is collected, treated and cleaned with specific products. At this station, a coagulant sticks dirt together to form a slurry which is then recovered in a clean-up operation. The coagulant is a powder stored in a hopper and then diluted in a tank with water. An agitator stirs the mixture constantly to keep it as slime. The laboratories decided to switch to another product which required the replacement of the old product contained in the tank with the new one. This operation was to be performed by a subcontractor.

That day, in the presence of the subcontractor, the facility operators isolated the plant, that is to say they put the system in a safety state (turned off) so that the subcontractor company could access the installation. A first operator turned off the power and put a warning label in the switch cabinet (a label attached to the cabinet) to indicate that this facility was off. Then a second operator cut the supply of water and locked the water valve off. The subcontractor had 2 hours to perform its work.

Once the installation is isolated, the operators communicate and coordinate with the subcontractors in a room called "the coordination unit". Work permits are delivered and signed by the supervisory team (called in French “Feux Constants” - FC), which authorize the contractors to work on the site. When the intervention has been completed, the subcontractor goes back to the coordination unit to sign off the completion with the FC. These put the installation back in service and send in Maxigès a report of the intervention.

The resolution of an anomaly is defined as "*any action that contributes to good functioning of the facility*" (Source: Energy department internal documentation). The intervention reports are treated in a maintenance meeting during which the actions taken are described and validated. We did not manage to collect very much data on these intervention reports but we were told that these reports are largely limited to observations about the technical resolution of the anomalies detected.

This section has presented how anomalies are detected and treated in normal operations. However, the accident analyses have shown that certain information remained unknown to this system of information management. The following section offers three lines of explanation for this problem.

5.4.1.1.3 Persistence of technical failure: three factors of explanation

****Works maintenance time scales and complexity***

The technical anomalies severity scale used by operations and maintenance operators, allows them to determine the severity of the failure (blue or red label) and the priority of treatment of red labels anomalies (priorities 1, 2 or 3). This shows that maintenance is organized along two dimensions: time scale and priorities (depending on severity). Thus, if an anomaly is an emergency, it will be listed as priority 1. However, if an anomaly is not seen as an emergency, it will be listed priority 2 or 3.

In terms of the treatment of technical anomalies (which is what interests us in this section), the data we collected are not complete, but we have a first hypothesis. The more works are a priority, i.e. curative according to the EDIA severity scale, the more the works organization is simple, which implies the use of the pre-agreed annual PP and risk analyzes, the fewer are the actors involved in the works, and the more local (limited to the area where the problem was identified without any coactivity between contractors) the work is. In contrast, the more the works are a low priority (preventive), the more their organization is complex – it requires a specific PP and risk analyzes implying many actors in this process - and the more the work is centralized in one or two centralized functions in order to coordinate the PPs and the high coactivity.

We assume that the simplicity of organization of the curative works goes with a lack of depth of analysis of the origins of the deviation and might help us understand the possible recurrence of these anomalies and the relative failure of ACIO to deal with latent causes of technical failures (item discussed and developed in section 3.1.2.3).

**Information filtered out*

The system of reporting technical failures would appear to represent an effective communication scheme for known types and causes of failure, because it would appear that it allows the detection, transmission and processing of information related to these sorts of technical deficiencies in a broader context of maintenance planning. But, as we proposed in Chapter 4 (EDIA Case study), it can be seen to be a closed communication system (figure 26).

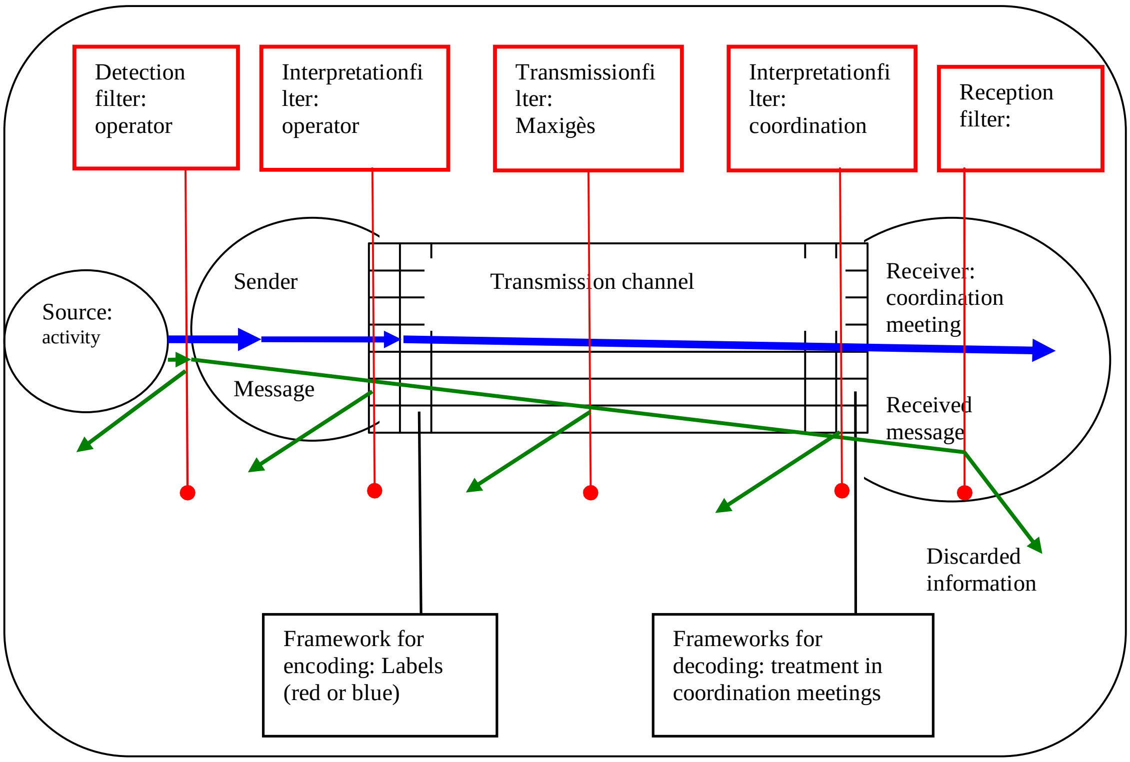

Figure 26: Closed communication scheme applied to technical anomalies reporting system (Maxigès), ACIO.

On the one hand, it only allows for the transmission and processing of technical failures and causes - in other words it only takes into account information fitting into the existing frameworks of interpretation and discards other information which might fall outside these frameworks, but could help to integrate the different pieces of information. On the other hand, it is a closed communication scheme because the Maxigès database is only marginally linked to other databases (for example accident analyses, Rex forms and behaviour audits).

Modification and revision of the system of reporting of anomalies: what learning?

Finally, this system of reporting and treatment of technical anomalies does not seem to include, at least according to the observations and interviews we conducted, any critical analysis of the effectiveness of the system. Indeed, given the persistent weakness of the first signals identified in accidents 2 and 3, we question the ability of the ACIO site to identify concerns with, and question the effectiveness of, their maintenance plans. We hypothesize that this reporting system limits the first phase of diagnosis and treatment to the technical dimension, without analyzing either the underlying causes of these anomalies or the reasons why some recurrent anomalies persist.

Indeed, faced with an anomaly requiring immediate and simple corrective intervention, we believe that the anomaly and intervention report and the determination of the cause of the anomaly are all limited to the procedural or technical dimensions. In addition, no relationship is made between technical anomalies detected and accident analyses, despite the fact that technical failures contain important and relevant information which, if they were related to accident analysis, could contribute to a better understanding of the causes of accidents. We would go even further; making a link between technical failures and accident analysis would be a big step in linking the information held by different people (operators and managers) fragmented across the organization and thus help in making sense of the weak signals of accidents.

Three important elements have been identified.

-The first is the use of a simple severity scale which defines priorities for treatment. This scale organizes maintenance in three broad time scales: short, medium and long term. There would appear to be a correlation between simple curative work and the simplicity of their risk analysis and identification of the causes of these anomalies.

-The second element is the nature or quality of the information processed. The communication scheme underlying the system of anomalies reporting appears “a priori” to be closed, hardly presenting any possibility of reporting and dealing with "surprises" (see section 2.3.2.2.1), thus discarding any information of a deviant (or unexpected) kind and not providing a connection between different databases (technical [Maxigès] and safety data for example).

-Finally, this system of reporting of technical anomalies does not promote critical analysis of its underlying principles and hence does not permit assessment of its own effectiveness.

The ACIO site therefore has difficulties in observing and analyzing the recurrence of certain problems (in other words in amplifying them) and turning them into real knowledge about emerging risks. Some underlying causes of technical faults therefore remain latent.

5.4.1.2 Contractors operations: a complex system for ensuring the safety of a maintenance site

The purpose of this section is to identify the activity in which the weak signal "lack of coordination between subcontractors and operators ACIO" finds its roots. It focuses on programmed stoppages: preventive, planned maintenance, complex to organize. For this we will return first to the specific prevention plans, required procedures for carrying out such maintenance work and, secondly, to the coordination meeting, a procedure provided by the specific prevention plan, designed to anticipate and manage changes occurring during such work.

5.4.1.2.1 Upstream: « administrative » preparation of works

The Prevention plan (PP), as a necessary procedure for the completion of the works, aims to ensure the safety of the staff and facilities during the three stages of work: upstream (preparation of official documents such as work permits, which will particularly interest us), the interventions themselves and downstream, the close-out of operations. During this process, different stakeholders (operations and maintenance) are involved, as key links in making the work site safe for maintenance.

Safety studies and information for the subcontractor companies

Some intervention requests may require stoppage of one or more facilities. This is a scheduled shutdown. On these occasions, works management profit as much as possible from each shutdown, that is to say they take the opportunity to plan for as much preventive maintenance or curative maintenance works as possible:

> *My role is to make any stop as short as possible, so we plan in the maximum number of people during a stop. A facility under a shutdown is a process that is missing. While stopped the quality degrades….. so you want to minimize the stoppage. While we are stopped we try to combine interventions in order to profit as much as possible from the stop.. " (Employee Maintenance Cast Iron)*

In the case of a scheduled shutdown, we observed a specific organization of the work (especially that of the work on converter 1). Several functions are specified:

-A shutdown (or project) manager who coordinates the work (as in accident 1). He is often a technician of the department concerned,

-A person responsible for the development of the PP (often the maintenance operator),

-A zone manager (supervision of work in the field).

We have not been able to confirm whether these actors are detached full time and are always clearly identifiable by all stakeholders (sub-contractors and ACIO operators). This question is still interesting because they provide the quality and the means and functions essential for the workflow.

Usually, and certainly in the case of the works on the converter, outages (or works which require to stop facilities for a long time) involve several subcontractors in the same area of the site. It is therefore necessary to analyze risks related to coactivity between different companies. The PP in the case of shutdowns follows a precise procedure. Once the relevant anomalies have been identified and intervention requests have been transmitted in the Maxigès software, the work of the different subcontractor's fitters is coordinated. The steps are as follows:

-Selection of subcontractors.

ACIO site does not really invite tenders; there are subcontractors with annual contracts and subcontractors with whom specific contracts have been signed.

-Safety studies.

Subcontractors must provide to ACIO safety studies, that is to say, a risk analysis of the activities they will conduct in the project. Coactivity analysis aims at coordinating the different operational phases and the risks inherent in them to prevent any risk of accidents to subcontractors and ACIO staff:

> Example: inspection work in a steel plant gasometer (gas holders are monitored (see prevention of major accidents section 1.3).
>
> Gas is stored in a gasometer before being sent to the facilities for use. The steel works gasometer contains 100,000 cubic meters of gas. Every five years, a general inspection is organized. The work includes an inspection of the internal structure of the gasometer to detect any corrosion and prevent any leakage of gas. 19 safety studies were submitted by the subcontractors covering the work.

-Planning visit to the worksite.

The zone manager invites the subcontractors to visit the place where work will be done, and observe the risks of the work area. This is, again, a legal requirement that certain people doubt the effectiveness of:

> *“We take companies into the field to show the context and show how they can work in coactivity. The problem with this visit is that there can be thirty of them and they do not necessarily hear everything because of the noise, and they are not always interested in all the points. What is more valuable is the meeting room where we summarize the important points " (Project manager)*

-Briefing.

A meeting in a meeting room, organized by the project manager, aims to remind the contractors of the work flows and risks associated with coactivity. Companies must sign an attendance sheet. The information meeting and the site visit let the subcontractors know the risks associated with any coactivity.

-Upstream, the preparation for the scheduled shutdowns.

It consists of an analysis of the risks inherent to works to be done. Several actors are involved: subcontractors, PP manager and zone manager. This procedure aims to predict and anticipate risks in a context of significant coactivity. But the operational reality in which the work is done shows that this procedure may be inappropriate (we discuss this point in Section 3.1.3).

****Operational preparation of Works***

Two steps must be met:

-The making safe of equipment. The equipment on which work will be performed must be made safe. This means isolation of the equipment, lock-off and tagging. This procedure is carried out by the isolation manager (usually a technician). It should guarantee staff and equipment safety (but see accident 1, ACIO),

-The intervention request transmitted in Maxigès becomes a work order and delivers a work permit.

Subcontractors are not allowed to handle live the installations on which they intervene (isolation and return to service)[45]. The isolation process avoids, precisely, any risk of manipulation by subcontractors. Equipment is isolated, locked and tagged by ACIO personnel. The subcontractor must get the certificate of isolation from the responsible isolation supervisor, and the work permit delivered by the works area manager. The work permit is the official document that allows subcontractors to work on the site. Accident 3 specifically revealed a weakness in the system of work permit allocation. If the planning changes, due to delays, as in the case of the bulldozer operations it should be notified. However, in that case it was not notified, so we assume that the work permit was also not changed. Company 2 appears to have worked with an expired or nonexistent work permit. This issue will be raised again later.

[45] There is one exception, a maintenance company ELEC Electrical equipment can handle low voltage equipment.

Works

Subcontractors can work on the site once the equipment has been made safe and once they have obtained their work permit. Work is supervised in the field by an area manager. Here, coordination is important (see accident 1, ACIO). Although the PP sets out all necessary operations to achieve the intervention, a change should lead to a modification of the initial PP. Any changes must be notified and sent by the person responsible for the work to the prevention plan coordinator, using a form included in the PP (see appendix 14).

The modification of the initial PP must be coordinated between the subcontractors, the area manager and the PP coordinator. Modifications can concern:

-The addition of a new subcontractor in the works area,

-The addition of new operations,

-Coordination between several different works areas (and thus between several prevention plans),

-Changes in risks present because of the coactivity between contractors and ACIO employees.

Therefore, a revised prevention plan includes a revised risk analysis based on coactivity between subcontractors newly assigned to the work and the existing ones. An internal note (dated 2007) written by an operational manager and included in the PP related to the converter works (prior to the accident a), states in this regard:

> "The daily coordination meeting related to work on the converter takes place at 10.30. We remind everyone of the importance of participating in this meeting. We ask contractors or technicians responsible for the area to analyze the progress of their work with the service providers (monitoring and updating the schedule details) in advance of the meeting coordination. This information should be communicated to the project manager by those responsible one hour before the coordination meeting. Compliance with the schedule should be a goal for all. Remember that the programming operation has been performed, in most cases, by agreement between ACIO and the subcontractor. **Failure to comply may result in coactivity and uncontrolled hazards[46].**

The prevention plan provides for coordination in a context of work and high coactivity between subcontractors and ACIO staff. This allows for the review of the safety studies carried out by the subcontractors and the analysis of any coactivity, and thus the establishment of safety measures adapted to the changing operations. The flow diagram for the prevention plan is set out in figure 27.

[46] Stressed by the author.

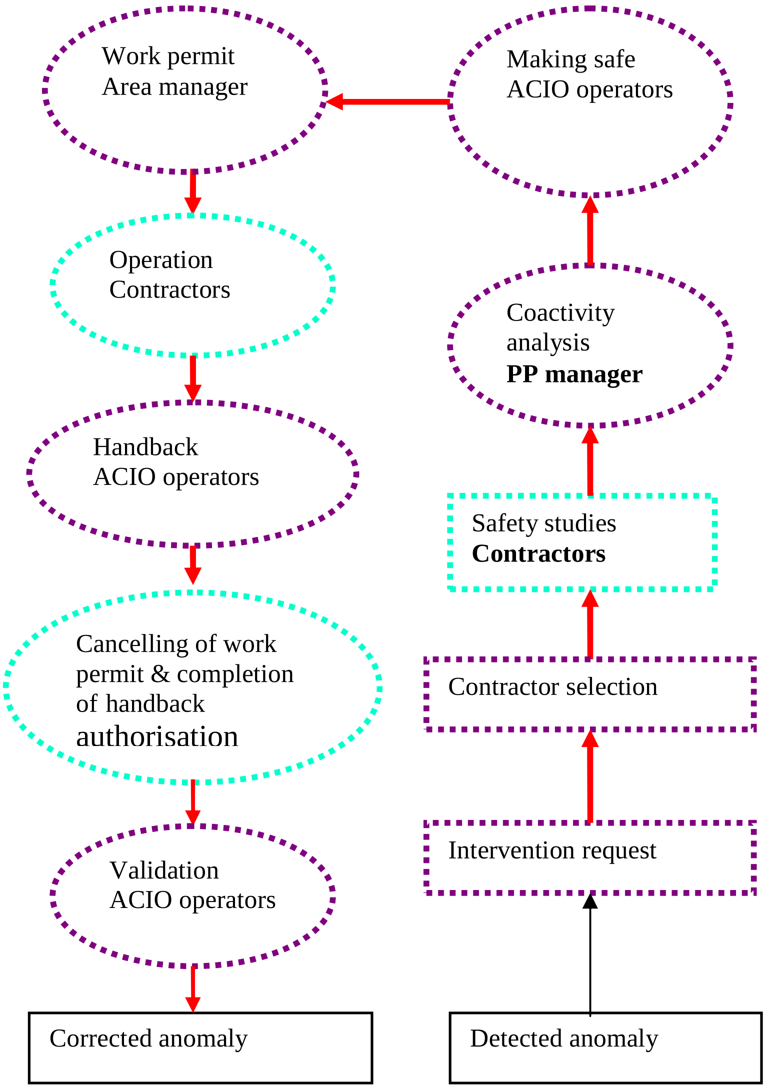

Figure 27: Prevention plan design for planned outages (or maintenance works), ACIO.

Legend: purple circles - ACIO operators, blue circles - contractors. Bold : people/functions in charge of the operation.

5.4.1.2.2 Downstream: the completion of work

After completion of the work the subcontractors return their work permit to the area manager (supervisor of works in the field). A document entitled "work completion"" is then signed, validating the fact that the operation has been completed. ACIO operators put the equipment back in service (removing the tags, the locks and handing the equipment back to the control of operations). In the case of planned outages, tests are performed before the handback of the equipment. The resolution of an anomaly is defined by the Energy department as "*any action that* *contributes to the good functioning of the facility*" (source: internal documentation, Energy department). A works report is communicated via the Maxigès software.

5.4.1.2.3 Prevention plan: a complex and centralized process

The previous section has highlighted the process of making personnel and facilities safe during planned maintenance works. We saw that work situations involve coactivity between the interventions of subcontractors and ACIO employees. Risk, due to this coactivity, is analyzed and taken into account in the Prevention Plan document, which is designed to ensure safety: upstream, during work operations and downstream.

In section 5.4.1.1.3 we distinguished two types of works: a simple and local procedure, and a complex centralized one (the case of planned maintenance work). In contrast with the simple curative work, complex work is carried out with the application of a specific PP characterized by centralization:

-Centralization of actors because of the multiplicity and geographical dispersion of the actors involved in the application of the PP (subcontractors and ACIO staff and, within ACIO staff, those involved in maintenance and operations) which requires the centralization of the main steps of the PP which we have described above (preparation of the PP, allocation of work permits and proof of isolation of equipment),

-The creation of coordination mechanisms (the PP and coordination meetings),

-Revision of safety studies designed to coordinate activities to avoid any accidents which would be related to coactivity,

-A long and centralized process for delivering permits to work.

Is the complexity of these specific prevention plans matched, unlike curative works, by a greater depth of risk analysis upstream and downstream of the interventions? Again, we do not have sufficient data from a small number of cases to provide satisfactory proof. We hypothesize, however, that, despite an initial analysis of coactivity, the risks identified remain limited to those related to compliance with procedures, and to correct behaviour and equipment use, and where necessary, a subsequent revision and modification of the hazard studies carried out by subcontractors without questioning the overall effectiveness and applicability of the Prevention Plan.

Thus, if risk analysis remains limited in the contexts of both simple and complex work, can we conclude that it represents a weakness in the safety management of the ACIO site?

Work characteristics	Simple/Local	Complex/Centralized
Coactivity between contractors	Little coactivity	High coactivity
Nature of work	Curative or priority 1	Preventive or priority 2 & 3
Nature of prevention plan	Annual	Specific
Safety studies	Not modified (included in annual PP)	Updated and modified within coactivity management
Work permit	Simple procedure	Complex and long procedure (integration of new risks from coactivity)
Plan prevention organization	Simple and local (few actors involved)	Complex (many actors involved) and centralized
Risk analyses upstream and downstream	Simple	Simple

Table 4: Summary of the two processes of work organization: simple and complex, ACIO.

The analysis of the way in which the Prevention Plan for planned maintenance stops is worked out is important because it helps to remind us of the context in which coordination meetings (the topic of the next section) are implemented. The latter, like PP, are characterized by a complex and centralized procedure, which in our view represents the main obstacle to its implementation.

5.4.1.3 Coordination meeting obstacles

5.4.1.3.1 Closed communication scheme and centralized procedure

We showed earlier (section 5.4.1.2.1), that a coordination meeting is set up to revise risk analyses when a change occurs in the initial schedule planned in the prevention plan (introduction of a new subcontractor for example). It gathers together contractors and ACIO staff to identify and anticipate the risks associated with this change.

We were only able to observe one coordination meeting in person, but all of the other data collected in relation to planned maintenance works (the gasometer maintenance and work on converter 1) allow us to conclude that coordination meetings are also characterized by centralization and have the following steps:

-Notification: the area manager is the main (and often the only) detector and communicator of any changes in the performance of work,

-Transmission channel: the information is transmitted from the place where change has been notified (locally) to the recipients (decision makers),

-Two centralized recipients: project manager and PP coordinator.

Planned maintenance work stops the plant for a fixed term during which the work must be carried out. Any change from the initial plan requires a rapid response (to match the context in which it occurs). However, the complexity of the coordination meetings, and also the time it takes to carry them out, can be seen as obstacles. The centralization of the procedure, inadequate at least in the case of accident 1, would have encouraged the use of an informal system of communication that could have avoided this complexity, a set of communication channels which could provide a local response adapted to the (time) constraints operators have to face.

5.4.1.3.2 Informal adjustments in response to complexity

The coordination meeting is a measure that should allow the management of the interfaces between subcontractors and ACIO staff when a change in the original PP has to be taken into account. The analyses of accidents that we have made, particularly accident 1, have shown that there is still a lack of coordination between subcontractors and ACIO staff.

Given the constraints posed by the process of the coordination meeting, subcontractors and staff ACIO seem to have developed new modalities of coordination. We did not observe a blurred sharing of tasks, as in the EDIA refinery, but rather a regulatory mechanism that allows an adaptation of the work interfaces to the context of the work. This informal regulatory mechanism is constructed in a "zone" where the rules and procedures developed and put in place by the organization are failing. The actors take advantage of this failure in order to build new rules (or regulations) that fit better to their personal goals but also to the context in which they workas the employee of Company 2 did in the case of accident 1, taking the responsibility on himself to start his delayed work without going through the formal change system.

"In theory, when there is a change in schedule, there is a new coordination. But this is not always the case"
"Why, when everything is planned to do so?"
"Lots of cronyism "Can you do this for me" and he does. It's also laziness, we say to ourselves that there is no risk and in 90% of cases nothing happens ... but if tomorrow there is an accident, there will be trouble. The PP is made for this, to avoid an accident. There is not always a coordination meeting for changes ... That's why we need a coordinator (project manager). But this is not a proper job position in itself, is often a technician who is assigned to coordinate the work " (Employee of Energy department)

These new rules may lead to professional practices that threaten safety (as we mentioned in the analysis of accident 1). These practices may not be perceived as sources of danger. Although they are known (see section 5.3.1.3.2) these practices seem still not to be dealt with or regulated and can become routines that normalize what started as non-compliance with the procedure.

The persistence of these informal practices between ACIO staff and subcontractors, as a response to the constraints posed by the formal coordination meeting, defines precisely a weak signal of an accident (see section 5.3.3.4.5). It is characterized by the difficulty in giving it meaning at the time - the link between these informal practices and threats to safety is neither direct nor clear - but also later, manifest in the difficulty to handle it during the Rex process but also by the difficulty to take it into account in event analysis.

5.4.2 Tools for reporting and treating safety anomalies

As in the case of the EDIA site, ACIO has implemented many tools to report, analyze and correct the anomalies and accidents detected on the site. This section provides an overview and analysis of these tools.

Our observations on the normal operation at ACIO have led us in a second stage to a further analysis of ACIO's safety management. This aspect of normal operations will serve to raise the issue of the risk analysis of the plant and the behaviour of the workforce, by dealing more specifically with the tools developed and used to detect, analyze and learn from significant events and anomalies.

Two questions guide our thinking:

-Why do some weak signals remain undetected despite the application of these tools?

-What tools could enable better detection and effective treatment of these weak signals?

In contrast to the EDIA refinery there is no department of Quality, Safety and Environment. ACIO has a Human Resources Department covering medical, safety, quality and internal affairs and a Major Hazards service reporting to the directors. Although attached to the central safety service (see figure 19), most of the safety staff are assigned to an operational department: two in steel-making, two in the smelter, one at the Energy department and one in the strip mill. Their role is to bring their expertise to the departments and ensure the maintenance of the level of safety at the workplace.

The following sections describe more precisely the tools used by the safety staff to ensure health and safety in the workplace. Interviews and observations conducted during our case study on the normal operation led us to identify two types of tools:

- Proactive Tools "upstream" of events: behaviour audits and prevention plan audits
- Reactive Tools, "downstream" of events (feedback): fault tree analysis and the Rex form

5.4.2.1 Proactive tools

5.4.2.1.1. Behaviour audit

****Behaviour audit characteristics: an open communication scheme?***

The behaviour audit is the main tool used by preventionists (in terms of frequency of use). It comprises the following steps:

-**Detection**: transmitter and transmitted message.

The behaviour audit enables the detection of two types of items. On the one hand, observable behaviour, such as the non compliance with a cardinal rule[47], failure to comply with an instruction (rule, procedure), and unsafe acts and unsafe conditions. The auditors do not describe the items observed but indicate the number of anomalies observed for each category. On the other hand, the auditors evaluate the knowledge of the people audited about safety principles (and particularly the cardinal rules). They measure the quality of training and communication of safety issues transmitted by managers to their operational teams.

> Audit of behaviour: Observation 1
>
> The audit is performed by the preventionist and the manager of the team being audited. It covers two operators of a subcontractor. The first one is responsible for moving a locomotive according to instructions received by walkie-talkie and the second one to control the traffic from a control room.
>
> The preventionist asks the first operator whether he knows the cardinal safety rules. The operator cites three cardinal rules: priority to the train, working at heights and gas danger. The preventionist then asks if, in this area, the operator must wear a gas detector. The operator says that usually he carries it but now today he forgot it. The prevenionist tells him that the area of the blast furnaces may contain CO. The preventionist asks him to fetch the detector. The operator returns with the gas detector and puts it on.

The behaviour audit, in addition to its formal dimension, offers preventionists the opportunity to observe work situations more broadly:

> *"There are other positive things. For example, it is hard for us to see welders actually donning their helmet and welding hood. Here we see a guy who wore both. In fact, talking with him, he explained that he had adapted the hood to be able to wear with a helmet. If we had not discussed with him during an audit, we would never have known. The goal is to have the opportunity of talking to people, discussing safety with them" (Preventionist)*

The audits are therefore an interesting way to detect, down at the work station level, not only defects but also what can be defined as "good practices".

-**Interpretation**: the chart of observations.

---

47 The ten cardinal rules are principles of safety that any operator working on the site must comply with. They are under development, with, so far, only three in operation (the seven others were under development): priority to rail (for traffic and crossing the tracks), safety rules for working at height, the evacuation gas alarm. These cardinal rules are based on a pyramid model of safety management (principle of the pyramid of Bird). At the summit of this pyramid are serious accidents and at the base near misses and risky situations. The theory is that the more risky situations are identified and corrected, the more serious accidents and near misses will be avoided. Audits are intended to identify these risky situations.

Observations are reported on a behaviour audit form. It provides four fields to fill in: positive comments, unsafe acts/ anomalies of behaviour, measurement of the effectiveness of communication on safety issues and action plans needing development. These fields correspond to the two categories of items that the audit can observe. The items are not classified according to severity (as is the case for site visits conducted on the EDIA site) but the number of abnormalities is observed for each item.

> Audit of behaviour, Observation 2. Audit of positive behaviour:
>
> In the control cabin a shift boss, a woman on a temporary holiday contract (THC) and a new hire are working. The preventionist explains that the THC employees are hired for one or two months in the summer and are usually trained only in the risk of the tasks they perform. Their training is provided by a mentor who accompanies them throughout the duration of their contract. ACIO pays particular attention to THCs because of an accident the previous year in Spiker. A THC got her hand crushed in a machine with many adverse physical and psychological effects.
>
> The auditor asks about the THC's task: she says she is carrying out sampling (on raw pellets). The preventionist sees that she is wearing a gas detector and asks if it works. She replies that it is turned off because she is in the control room, but she puts it back on when she takes the samples. He then asks what she has to do if the detector lights up. She replies that she must evacuate and call someone.
>
> We then see her take a sample. She takes her walkie-talkie, puts on her earplugs and helmet, and turns on the gas detector when she goes out into the plant (THCs can work alone in the plant). On her return, the preventionist then asks if she has a mentor. She immediately gives his name.
>
> As we leave, the auditor tells me he wanted to check if she had understood the dangers of gas. The message has clearly been understood by the THC in his view and this positive observation is noted in the report of the audit.

-**Treatment**/analysis.

The audit reports are made by the auditor and recorded in a database devoted to behaviour audits. They are sent to the head of each operational department where the audit was completed, to the safety service manager, and to the shift manager of the people audited. The anomalies detected must be dealt with by the person responsible (who in most cases is the team leader of the sub-contractor whose operators have been audited). The preventionist is responsible for monitoring the implementation of actions, the quality of the analysis and that of actions.

The analysis and recommendations are worked out by the (sub-contracting) company audited and monitored by the preventionist. The latter sets the response time.

Behaviour audits are recorded in a database specific to this information and managed by the safety service. They are strictly accounted for (we recall that every preventionist must conduct one audit a day, operational managers twenty per year). For example, the smelter department conducted 710 audits the year we carried out our case study.

> Audit of behaviour, observation 3:
>
> A truck driver is transporting lime for discharge into a lime storage silo (using an air line connecting the truck to the silo). He is in shorts and t-shirt, wearing a helmet and shoes but no goggles. The auditor asks for the safety protocol for this operation. The driver climbs into the cabin and fetches a book from under the seat. He searches for about five minutes, then gives a document to the preventionist, but it does not match what was requested. The second document he hands over is correct but incomplete; it is the safety protocol agreed between the subcontractor and ACIO describing the procedure for unloading and the safety equipment required for this operation. It says that the driver must wear safety glasses, helmet and shoes. The auditor calls the team leader to tell him of the non-conformity (incomplete procedure and not wearing safety glasses). The latter calls the head of the subcontractor company, who will take the necessary measures. The preventionist returns to the driver and tells him he may finish his work. Twenty minutes after the audit conducted at the lime discharge station the auditor is informed by the manager of the truck driver that the anomaly has been dealt with. The report of the audit stipulates that the subcontractor shall submit a complete procedure for the discharge operation within ten days.

See figure 28 for a summary of the procedure for behaviour audits:

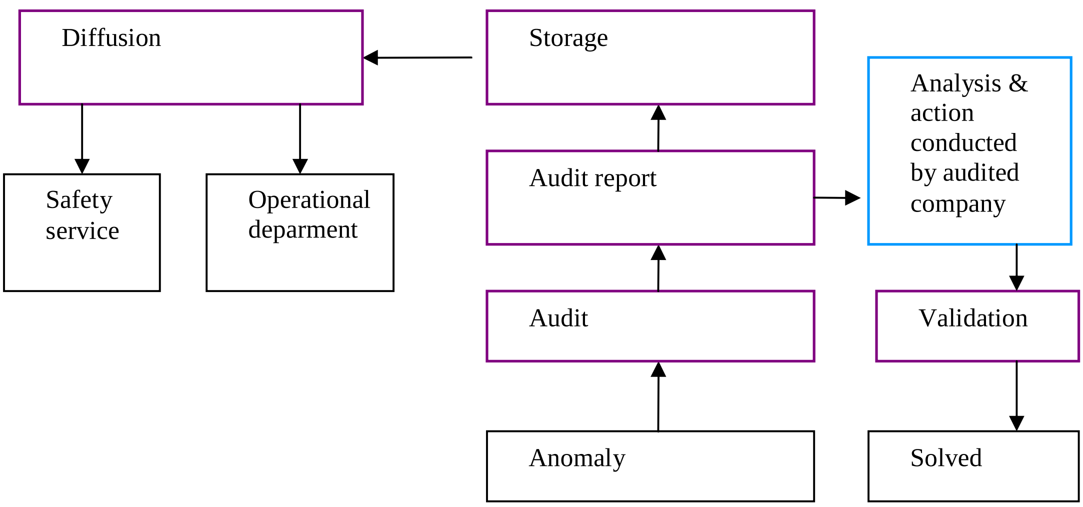

Figure 28: Scheme of behaviour audits, ACIO.

Legend: purple, preventionist. Blue: company audited.

Contributions and limits of the behaviour audit

Firstly, the behaviour audit, as framed in a formal guide, seems to encourage a posture of observation. The audit is indeed specified in this way, to observe a work situation before evaluating it:

> "On arriving at a workplace in the field, stop for about twenty seconds and scan the situation. In order: personal protective equipment, position and behaviour of people, ergonomics, tools, equipment and machinery, procedures and compliance with instructions, order, cleanliness and housekeeping" (Extract from behaviour audit form)

Observation of working situations could lead to expansion of the audit by the inclusion of data not listed on the form. Also the conduct of the audit is not limited, at least in theory, to the detection of violations of the instructions by the operator. The following quote from a preventionist is eloquent:

> *"In the new form, there is no rating of serious or not serious. For the item "Non-compliance with an instruction" it is always a risk of death because it is the top of the pyramid. But failure to comply with an instruction, it all depends on the type of instruction ...."*
> *"And this new formula, without severity scale...?"*
> *"We are only just starting with it…it is difficult to evaluate yet. For example, a guy who does not have a harness it is a violation of the rule but there is no severity scale (...) I think it makes you think, because a supervisor who sees many violations of safety principles (cardinal rules), will say to himself that people do not respect instructions. It is a reality. Before we always said it was behaviour"*
> *"And the violation of instructions, is that not behaviour?"*
> *Yes .... But it makes you think about how you communicate about compliance with instructions. The unit manager may say I need to "take up battle stations" on this one" (Preventionist)*

This would thus expand the spectrum of analysis, because it would lead not only to an examination of the operator's behaviour but also the ability of the hierarchy to transmit to the operators the basic principles of safety. Finally, the wide dissemination of the reports of the audits could ensure, in our view, the sharing of lessons learned from the observed anomalies. The audit report is sent not only to the safety service (central and distributed) but also to the operational department concerned, which ensures data is communicated from staff to line.

After these three observations, we suggest that, at least from its design, the behaviour audit could expand on the basic principles of a (closed) communication scheme, - the detection channels (using the form, but also observations), analysis and dissemination - and could also open up better links between the line and staff in the phases of detection, interpretation, transmission and treatment (see figure 28).

However, we observed several obstacles to this opening up. First, the conduct of the behaviour audits in the detection phase, finds difficulty, because of the design of the reporting form, in transcending a simple verification of compliance with procedures and “good” behaviour. Observations and interviews showed a very formalized reporting of anomalies, that is to say, filtered through the predefined anomalies (or items) on the behaviour audit form. The analysis and proposed actions to address the problems identified appear to be reduced to recall of and compliance with the rules and procedures. The opening up of the communication scheme that we considered possible, seems, in practice, to be reduced to an analysis focused on the behavioural and procedural dimensions – a process of verification and formalization, not of critical and creative observation.

Then, in the processing of data, the ACIO site does not escape two pitfalls. On the one hand, the accumulation of data seems to turn into an objective in itself (data collected through audits are very extensive, about 1,400 audits per year in the smelter) which, on the other hand, generates difficulties in processing the data. The very emphasis on counting the anomalies, rather than describing them pushes the tool and its use down this compliance, rather than problem solving path. However this is not inevitable. For example, the interviews carried out with preventionists showed that a behaviour audit could detect anomalies in operational safety such as the use or not of a coordination meeting:

“For example, last time we conducted an audit where a subcontractor brought a crane into a works area whereas it was not included in the PP. The works regulation says that any subcontractor must notify the ACIO project manager about any change of prevention plans, and we set up a coordination meeting. Subcontractors do not necessarily know about the coordination meeting procedure…” (Preventionist)

But, how does the operational department remedy this type of anomaly? Why, when detection tools exist, does the particular problem of the coordination meeting still persists?

In conclusion, the behaviour audit could provide, based on its design, a way of opening up the closed communication scheme: through its method of detection, through the analysis it is able to provide and through the extent of the dissemination of lessons learned. In practice, we noted two obstacles blocking this opening up of the communication: a tendency to limit the checking of anomalies to those formally defined a priori in the detection tool (audit form) and counted in the audit, and a weakness in the depth of data analysis. This links to a difficulty of the site to initiate organizational double-loop learning (we discuss this hypothesis in chapter six).

5.4.2.1.2 Prevention plan audit

During the execution of work the prevention plan document can be audited, using a prevention plan audit form. These audits may be conducted either by managers of operational departments or by preventionists. PP audit are designed to verify that all documents (constituting a prevention plan) are present, but also, and this is particularly interesting, if coordination meetings are conducted.

-Detection.

A prevention plan audit checks whether the upstream stage of the PP - that we called the "administrative preparation”- (see section 5.4.1.2.1) is respected. The following example illustrates how the preventionist can conduct a PP audit:

> Audit of the Plan for Prevention conducted by a preventionist:
>
> It concerns the replacement of a section of corroded Coke gas line. The new section is lying on the ground. Work is being performed by subcontractors of company 1 whilst another contractor company (2) is looking after the safety.
>
> Subcontractor 1 is currently welding the new line on the ground. The preventionist stops the operation and requests to examine the prevention plan. The team leader accompanies us to the bungalow where the responsible manager from company 2 is sitting. The preventionist wants to check the PP because, as a result of an audit carried out the previous week, there were parts missing (the procedure for assembling the pipe conceived by the sub-contractor, a sub-contractor of company 1). The operation is risky because, under the pipe which must be replaced, there is a gas pipe; if the two lines collide during the lifting operation, it may cause an accident. After consulting the PP, the preventionist manages to find only the safety procedure for the disassembly phase and not for installing the new pipe. The audit of the PP is non-compliant because of these missing parts.

The prevention plan audit then provides for a check based on documents on whether the coordination meeting has been set up:

> Extract taken from « Prevention plan Audit» :
>
> CHECK ACCORDING TO DOCUMENTS whether a coordination meeting has been set up:
>
> - Following the addition of new contractors,
> - Following the addition of new activities,
> - Following coactivity between different works areas,
> - Following changes in the risk analysis,

-Interpretation.

Items are "consistent, non-conforming or not applicable” and not rated on a severity scale.

-Treatment.

When items are assessed as "non-compliant", the auditor is responsible for ensuring that the company puts corrective action in place (observation 1 shows the role of the auditor). PP audits are recorded in a database and managed by preventionists or managers (if they are trained as auditors).

The prevention plan provides that subcontractors and ACIO staff account for the establishment and results of a coordination meeting by signing an official document. The audit seems, from our limited evidence, more to test the existence and conformity of these documents and less to consider the conditions under which, in practice, this meeting has been set up or not and what problems or changes have been identified and resolved.

In conclusion, the prevention plan audit and behaviour audit are two interesting tools. They allow:

-The detection and correction of anomalies before the event (proactive approach),

-The reporting operational safety anomalies, in particular whether a coordination meeting has been held or not.

It must be noted however, that in the case of accident 1 failure of application of the coordination meeting escaped both of these two tools. This could be due to the fact that during the detection, treatment and analysis stages, the anomalies processed are limited to non-conformities in documents and failures to follow procedures.

5.4.2.2 Reactive tool: the Rex process

We will now deal with the tools designed for analyzing accidents reactively. Two questions guide our thinking:

-What is the depth of analysis conducted via the Rex process?

-What is the depth and scope of the lessons learned from event analysis?

5.4.2.2.1 Contribution of the Rex process

The Rex process aims to reconstruct the circumstances of an event, to identify its causes and implement corrective and preventive actions. The objective is to learn from the event to avoid the repetition of it, or if there is repetition, to create barriers that will reduce its severity.

Our studies led us to make two positive observations. First, we saw the richness of the analysis results from the range of different analysis tools that can be used after an accident: fault tree analysis, Rex process, and in some cases a special HSC meeting or an analysis carried out by an external expert. Moreover, we observed a quite deep event analysis. The fault tree meeting (for accident 1) shows clearly ACIO’s ability to identify causes that go beyond the purely technical circumstances of the accident, such as the pressure exerted by the work completion time and the difficulty for the area manager to fill two roles (work supervisor and coordinator).

Secondly, the accident analyses used could lead to a breakdown of the barriers between departments. Maintenance, operations and safety, but also subcontractors (and members of the HSC) were able to confront each others views and understanding of the facts.

5.4.2.2.2 The Rex process, a learning approach?

However, our analysis of the Rex processes of accidents 1, 2 and 3 showed a relative failure in the treatment of three weak signals: a latent technical failure, a lack of coordination during planned maintenance and an underestimation of risk. Information about these was identified during the Rex processes carried out by ACIO; e.g. the repeated defects in cartridges was detected by the Energy Department and Oxyair (accident 2); the lack of coordination between the subcontractors and ACIO staff was stressed during accident meetings and raised during the fault tree meeting relating to accident 1. However, the ACIO site seemed to have had difficulties to integrate and treat these three weak signals in the Rex process. Although important, these findings did not seem to be taken into account in official documents (Rex forms, accident analysis reports). What factor, common to all three Rex processes, could block the possibility of treating them and learning (effectively) from them, particularly at the organizational level? We propose a number below.

Rigidity of risk perception seemed to block the learning process in three aspects:

-The tool. The feedback process seemed to be designed to pay attention to and process only information that fitted into the categories on the Rex notice- technical errors and non compliance with procedure. The more complex information, revealing organizational dysfunctions, seemed to get discarded during the process, before it could reach the recommendations.

-The actors' risk perception. The difficulty of perceiving or imagining the risk and the limited identification of the causes which lead to an accident could contribute to the difficulty to detect and treat weak signals. While the issue of subcontractor coordination was raised during the fault tree meeting (accident 1), participants did not dig deeper and directly address two fundamental questions: the effectiveness of the system for allocation of the work permits and the adequacy of the procedure for the coordination meeting within the context of work.

-Organization. Finally, following on from the questions raised above, the ACIO site did not question the organizational failures underlying the problems identified (weakness in the analysis of recurrent anomalies in accidents 2 and 3). In other words, ACIO site did not seem able to initiate organizational double-loop learning.

The rigidity of the perceptions of risks limited the learning to a first level : practices (behaviour) and procedures. Taking account of weak signals remained difficult. The link to safety was too indirect for them to be seen clearly as a threat. In view of these difficulties related to the rigidity of risk perception, inherent in both the Rex process (tool) and the interpretive frames of actors and the organization, the ACIO site failed to achieve organizational double loop learning.

In conclusion, the study of normal operation has yielded the following. First, despite the existence and use of tools for reporting anomalies - Maxigès for technical anomalies, behaviour and prevention plan audits – the information coming from weak signals (identified in Part II) are hardly taken into account in the Rex process. These tools seemed to be designed more to accumulate expected (filtered) data (that is to say, categories defined to be taken into account by Rex) rather than to make sense of them, since we did not observe any method to identify the causes of repetitious anomalies, or to identify organizational patterns underlying the emergence of these signals. The effectiveness of these analysis tools within their defined limits is not called into question. However, it became quite clear after our analyses of the accidents proposed in part II, that the repetition of the technical fault on the cartridges (accident 2) had a clear connection with the subsequent accident sequence, and similarly, the persistence of poor maintenance of the roof of the silo (accident 3) also had an impact on the circumstances of the accident. Thus, we hypothesize that, if ACIO had a method to identify and solve repetitive and persistent technical failures, the accident sequences could have been identified earlier.

In addition, we found out that the event analysis conducted following an accident, was limited to two levels: causes identified were mainly technical and procedural, and actions proposed to solve the problems seemed to be confined to the recall or reinforcement of the procedure and did not question the principles underlying the design of the technology or of the procedure as causes of an accident (for example the maintenance plan). This analytical weakness is due, according to our hypothesis, to a rigid or narrow risk perception which blocks the integration of complex information into the analysis, which would reveal the underlying organizational dysfunctions of safety. This reflects a tendency to consider only the known risks for which tools and analysis processes are designed and mobilized, and to discard or ignore unexpected risks or signals that question these “rigid” tools. In relation to the processing of weak signals, which we have defined as information that does not fit within the designed frameworks of analysis of a closed communication scheme, we hypothesize that the ACIO site does not have the capacity to challenge and open up these rigid frames, both procedural (the tools) and cognitive and organizational, to consider and integrate new and "dissonant" (unexpected) information characterized by its informational power of anticipation. This refers again to the notion of "organisational double-loop learning" which implies an ability to challenge the management tools and procedures but also the organizational principles underlying these practices.

Finally, to summarize, ACIO site seems to suffer from the lack of a method of accident analysis which would enable on the one hand the identification of relevant information - characterized by repetition or by its rooting in the way the organization normally operates, but difficult to collect because of their indirect relationship with safety - and, on the other hand, the linking of this information with other sources of information to make sense of them and transform the information into knowledge about the accident sequence in question (and by extension to other accidents).

The last section of this chapter raises the following question: are the weak signals identified merely specific to the three accidents analyzed in the second part, or are they structural defects, embedded in the characteristics of the organization?

5.4.3 Organizational fragmentation and rigidity of risk perception: effects on weak signals treatment

The study of operations during the accidents enabled us to identifying three weak signals of accidents: latent (repetitive) technical defects, lack of coordination and an underestimation ofrisk. For each of these weak signals, we have attempted to determine what, in normal operation, would allow us to understand the persistent weakness of these signals.

This section aims to provide answers to the following two questions:

-Are the "roots" of the weak signals of accidents specific to the three accidents reported in the second part?

-Are these roots structural, that is to say that they reveal shortcomings of the organization?

The answers that we propose summarize the results presented in this chapter and suggest lines of action to take better account of the weak signals of an accident that we have identified.

5.4.3.1 Operations and safety management: two different organizational logics

5.4.3.1.1 Centralized organization of operations

The accident analyses and the study of normal operations which we conducted led us to identify two characteristics of the organization's operations.

In section 5.4.1.1.3, we first hypothesized that the smaller the number of actors needing to be gathered for maintenance work (contractors and ACIO employees), the simpler the work organization, the more locally it is managed, and the greater its capacity to respond rapidly to changes (exogenous or endogenous). In contrast, for maintenance work requiring a lot of actors, the organization will be more complex, centralized and unable to respond quickly to changes.

However, the context in which complex work is conducted requires to a certain extent also a rapid and local response (notably coordinating the activities of operators resulting from a change of organization of work). As a result, the less the operational modalities (the coordination meeting for example) are adapted to the environment, the more people will try to create strategies to bypass these modalities, specifically to adapt their work to the operational reality in which the tasks must be performed. The issue of how to adapt the organization of work raises its head. To decentralize and give explicit "flexibility" for transparent local adaptation and hence to prevent these informal “bypassing” practices may sometimes be in conflict with safety (this issue will be addressed in the final summary chapter 6).

5.4.3.1.2 Fragmented safety management

The safety management system applied on the ACIO site seems to be based on a fragmented model of data related to safety management.

Three levels of severity of event are distinguished: anomalies, significant events and major accidents. Anomalies (first level) are themselves split into two parts because they include technical failures transmitted through the Maxigès software, and behavioural safety anomalies detected and transmitted through the prevention plan and behaviour audits. At this level, we observed a weakness in linking and processing the two types of data together. The second level covers the event analysis approach (local event analysis, fault tree analysis and Rex form). Again, we found a lack of connections between data generated under these three headings and a difficulty to link them with data related to anomalies (technical and safety anomalies). Finally, the third level covers the prevention of major accidents (see section 5.2.3) for which detailed predictive risk analyses are conducted.

This distinction in three levels of severity seems to be based on Bird’s Pyramid, which, similarly to the EDIA refinery, seems to constitute the underlying model of safety management. The Bird Pyramid assumes that the more anomalies are detected and corrected, the fewer occurrences of major accidents there will be. However, as we indicated above, the fragmentation of databases that constitute each of these levels seems to show a lack of connection between the databases within one level of severity and across the three levels of severity. If the links between these data are not ensured, to what extent can the anomalies detected inform about the likely occurrence of a significant event or a major accident?[48]

[48] There is also a more fundamental concern about use of the Bird Pyramid (see e.g. Hale 2001), which we discussed in chapter 4, namely that not all minor events or anomalies are predictive of major hazards and hence great care has to be taken in linking databases of the different levels in order to draw valid conclusions.

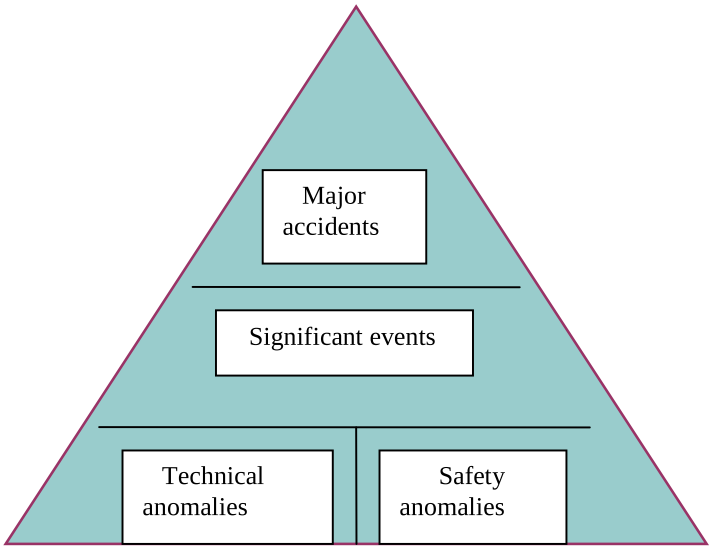

Figure 29: ACIO model of safety management, based on Bird's Pyramid

This fragmentation of safety management (Figure 29) presents a challenge to the ACIO site in identifying, integrating and taking into account relevant data predicting an accident. Instead, such fragmentation only strengthens the accumulation of data in separate databases, isolated from each other.

5.4.3.2 Process of information filtering

Within this fragmentation, a process of information filtering seems to generate on the one hand amplification of the formal data related to safety, which matches the categories designed to be processed in the system of information management. For example, the Maxigès software seems to be uniquely designed, in its detection, interpretation and data processing stages, to take account of technical anomalies detected on equipment. On the other hand, this filtering mechanism tends to eliminate or weaken the messages carried by other data which do not fit within the frameworks defining that information management system, e.g. underlying design or organizational issues.

As we found on the EDIA site (see Figure 17, section 4.4.2.2.1) filters seem to play a role throughout the communication channel and ensure amplification data designed to be coded and decoded in that channel, and weakening of data that fall outside the frameworks/analysis categories.

Organizational fragmentation leads to compartmentalization and thus a lack of linking between data: safety anomalies, technical anomalies, and between databases. Within these fragmented entities, the mechanism of information filtering (just described) seems to strengthen both the compartmentalization of databases and, consequently, to block any possibility of integration of data.

5.4.3.3 Risk perception

Consequently, risk perception seems to be an obstacle in the identification and treatment of certain information. Characterized by its relative "narrowness", it comes at three levels.

First, the tools in the Rex process – post-accident analysis meetings, causal trees and Rex forms - appear to block the identification of relevant information. Despite a capacity for extending the analysis to identify the organizational and environmental causes of accidents, (manifest in accident 1) event analysis seems to be based on a closed communication scheme, which essentially amplifies the proximal technical and procedural information configured to be transmitted and processed through these tools, and therefore filters data of a different type or configuration. For example, the recurrence of anomalies on the filters cartridges of the oxygen line (accident 2, ACIO) was not analyzed as a latent technical failure, or even included and integrated in the Rex process as relevant information.

Second, narrow risk perception could also be observed in the interpretive frameworks used by the actors (those participating in the event analyses), which represents a barrier to the treatment of weak signals. It seems to block their ability to identify the organizational complexity of accident causes identified (which the weak signals actually reveal). Their analysis is limited to technical or procedural treatment of these causes.

Finally, and this remains a hypothesis, the ACIO site seems to lack the material, human and organizational resources to conduct accident analyses of a depth that would allow them on the one hand to open up their analytical frameworks and adopt the posture that Weick called "prerequisite imagination" (this position involves the ability to imagine other scenarios or risk than those already experienced) and, secondly, to include human and organizational factors. Trainng to overcome these limitations, or the use of experts already trained in accident analysis, would be one way to implement a method allowing ACIO to identify underlying (and therefore more generic) factors of accidents.

In summary, the ACIO site seems to fail to engage in an approach that we could call "weak signals sense-making": identifying occurrences, linking data and questioning and revising their interpretation frameworks in organizational double loop learning (see section section 2.3.4.2).

5.4.3.4 Conclusion: lack of a global method of risk control

In conclusion, the ACIO site could be defined by the following characteristics:

-Complexity[49]: A complex organization of operational works, that is to say, segmented, centralized, relatively poorly adapted to the environment in which it is set up and relatively compartmentalized.

-A fragmented safety management leading to the compartmentalization of databases (anomalies, significant events and major incidents).

-Within this fragmentation, closed communication patterns which manifest themselves through the use of tools with predefined frameworks for managing data related to safety, a mechanism resulting in amplification of formal data, configured to be processed by the tool, and weakening of other signals.

-A narrow risk perception showing itself by event analyses limited to the technical and procedural dimensions (often only at the level of organizational single loop learning) and a difficulty in initiating organizational double-loop learning, that is to say identification of organizational causes of accidents but also the revision of the very principles of risk control of the hazards on the site put in place by the safety management system of the ACIO site.

These organizational characteristics could explain the difficulty of treating the three weak signals identified in the second part of the chapter. They show quite clearly the lack of global approach to risk control. Rather than thinking in terms of statistics or data accumulation, the method of risk control which Hale (2000) suggests, requires thinking in terms of scenarios. The objective is to define a requisite number of accident scenarios to cover all the known hazards in the organization and eventually to update them as new hazards are discovered. More precisely, the intention is not just the limited number of major accident scenarios currently defined, but to open the organization to new scenarios of accidents that can occur, and to identify as precursors of these scenarios, the material and human resources necessary to control them and the revision/learning criteria necessary to update them, based on analysis of relevant accidents and incidents, the relevance of these elements.

Once the scenarios have been established, this method requires two major activities. First, it is essential that the organization analyzes, for each database, single (precursor) events with high damage potential and recurrences of more minor precursors and anomalies detected, and links them with other information sources, including those in the other databases, that would provide additional insight into the origins of the precursors and repetitions. This activity would give sense to fragmented data and would be an appropriate vehicle to build, on the basis of such knowledge, indicators/precursors of accidents.

[49] This first feature applies primarily to the organization of planned work.

→This activity would help to resolve the problem of fragmentation.

The second activity consists in the establishment of double loop learning, that is to say, the evaluation and questioning of the tools devoted to detecting anomalies and significant events, and their underlying principles at three levels: the safety management model, risk perception at both individual and organizational levels, and the adequacy of the methods used in relation to the environment of work in the organization.

→This activity would help to resolve the problem of the narrowness of the risk analysis.

Thinking in terms of scenarios would lead the organization to identify, within the mass of accumulated data, what are relevant data actually informing about the potential occurrence of an accident, which need to be integrated in order to help to capture lessons learned from accidents and incidents/precursors. Finally, and this represents perhaps the most essential principle, the implementation of this method would require a strong desire to adopt a reflexive posture vis-à-vis the system of safety management and to initiate organizational double loop learning to re-examine the principles of safety management.

5.5 The role of the researcher in the learning process

The fourth and last part of this chapter is devoted to the evaluation of the methodology used at ACIO, action research. Unlike the case study on the EDIA site, I was not able to make the necessary feedback to fulfill the requirements of action research for two reasons: initial lack of availability on my part, followed by a very unfavourable economic context for the ACIO site which resulted in a sharp slowdown in activity, whereby the presentation of the results of my study was not a priority.

This part will focus on the active role I played in the analysis of one accident, whereby I will stress the contributions and limitations of action research.

5.5.1 Observer and participant

The relevance of the analysis of accident 1 lies both in the method set up by ACIO (for a near miss which could have been fatal) but also in the effect of my presence and participation in this process.

5.5.1.1 Opening up of analysis frameworks?

My participation in the event analysis was an opportunity to observe in real-time the method applied by the ACIO and the contribution I could make. My objective was to identify and incorporate organizational causes in the Rex notice and accident analysis. This meant that I postulated that (at least) one of the causes of accident 1 was organizational. This analysis work was conducted in two stages. With the preventionist, who was trained to perform fault tree analysis, who proved capable of taking a step back to survey the analysis method, I scanned all the possible origins of the circumstances of accident 1 based on information that we received from the responsible manager. Besides the material cause - the presence of the STT - we identified in the first version of the fault tree a work environment cause - work-pressure - and an organizational cause - the role of the area manager in coordinating the subcontractors.

Contrary to my expectations, all three of these types of cause we had identified and shown on fault tree - physical, work environmental and organizational causes - were admitted as legitimate and discussed during the two accident meetings. This revealed, in my view, a broader analysis capability (not restricted to technical and procedural reasons), a posture not observed on the EDIA site. However, although they were identified, the organizational causes were not treated thoroughly, in our view.

5.5.1.2 The downside of the inquiry…

Unlike accidents 2 and 3 (and three other accidents analyzed but not presented in this thesis), accident 1 occurred when I was present on the site. So, I had the opportunity to observe and participate in the investigation.

As mentioned in the second part of this chapter, the information regarding the circumstances of the accident remained repeatedly blurred or incomplete during the analysis. Therefore, the preventionist and I decided to investigate and find out additional data. We tested two informal channels. First, we met with the team leader of company 1 (who had not been present at the fault tree meeting). After a visit to the accident site with him, he pointed out a fundamental issue: the absence of the area manager during the operation of the bulldozer. He said he had been tempted, during the first post-accident analysis meeting, to point out this anomaly. He told us that as a subcontractor company, it was difficult to raise an anomaly that called into question the ACIO staff directly involved in the accident. He had therefore hoped that I would stress that problem myself during that first meeting. I would represent for him a neutral ally because I was not part of the organization and had no hierarchical relationship with ACIO employees. However, I did not perceive the “signal" that the company 1 team leader had sent me during this meeting probably because of the complexity of the accident circumstances and my lack of information.

As a second step, we wanted to elucidate the practices of bulldozer drivers in the STT area. We once again visited the area and interviewed two drivers. To the question "Is it common for an STT to be pushed by a bulldozer?" we got two different answers: it was common practice for one driver, but an exceptional practice for the other. Having received no unequivocal answer, we finally, without authorization, consulted the annual prevention plan available in the offices of the company 2. None of the written procedures in it allowed that a STT could be pushed by a bulldozer. We also tried repeatedly to obtain prevention plans related to the converter works but without success.

In conclusion, the inquiry after the accident seemed to be limited in the channels used by the (official) participants to collect information. Formalization of collection of information in informal or less normal ways – through observation of actual work situations – will be an area of recommendation addressed in the final chapter.

5.5.2 Information filtered out

I only analyzed the data I had collected on the ACIO site some considerable time after my period of immersion in the field. So it was only a posteriori that I understood why the information pertaining to the organizational dimension of accident 1 had been filtered out (not, or hardly appearing in the official documents of the accident: the Rex notice and the root cause analysis).

The communication underlying the two formal post-accident analysis meetings (the accident analysis meeting and the fault tree meeting) seemed closed, that is to say that only the information configured for these tools could be easily transmitted and processed there. Therefore, during these meetings, only some of the information was transmitted and processed, whilst other information was filtered out, namely about the system for allocating work permits and the reasons why the area manager was absent during bulldozer operation.

The rigidity of the risk perception frameworks of the people involved in the event analysis appeared to have reduced their capacity to identify the latter type of information as threats to safety because the link between this information and safety was not obvious and clear to them. On the other hand, it appeared to have reduced their capacity to identify the organizational dimensions underlying such information, particularly the adequacy of the system of coordination between subcontractors and ACIO staff in the context of maintenance work - because that requires calling into question the whole complex issue of the roles of sub-contractors and ACIO management.

The lack of attention to the issue of the absence of the area manager during the operations of company 2 (confirmed during my further investigation) means that there has been no further practical reflexion on ways to reconcile his two roles: as supervisor and as coordinator, and, in addition, the issue of adequacy of the complex and centralized procedure of the work permit allocation and the coordination meeting in the context of maintenance work, which is characterized by time pressure, and requires rapid and local responses to organizational changes.

My attempt to open out the frameworks of interpretation was limited by the constraints of the accident analysis approach applied in the ACIO site, but also by my own difficulty to elaborate an alternative detailed analysis in time (but does the work of analysis not require precisely taking time?) and to assert my position of researcher.

5.5.3 General conclusion

In conclusion, the ACIO case study led us to identify three main themes. First, we defined three types of weak signal of accidents arising out of the analysis of the three accident case studies:

-The persistence of latent technical defects

-Defects in the formal coordination between subcontractors and ACIO staff which could result in informal practices sometimes threatening safety

-Underestimation of risks.

Second, in order to understand the persistent weakness of these signals, we attempted to identify their roots in normal operation:

-Weak signal (A) appeared to be rooted in the failure to analyze the underlying causes of the technical anomalies (and their repetition) which were detected and recorded in the system anomalies reporting

-Weak signal (B) appeared to be rooted in the relative inadequacy of the process guiding coactivity management, particularly the inadequacy of the coordination meeting within the context in which work is performed

-Finally, weak signal (C) appeared to be the result of a rigid and narrow event analysis method. We observed this rigidity at three levels: in the tools used, in the actors/participants risk perception, and in the lack of organizational resources devoted to the analysis of significant events.

Thirdly, we investigated whether the defects or limitations identified above were limited only to the accidents analyzed in the second part of the chapter or whether they were structural, rooted in the organization, and therefore likely to be identified again in other events. We pointed to three organizational characteristics that may explain the persistent weakness of these signals:

-Organizational fragmentation or inadequacies in the administrative organization of work in relation to the realities of operators' tasks (can lead to the emergence of informal practices between operators to bypass the formal rules of coordination.

-Rigidity of communication schemes. On the one hand, the safety management tools designed to detect and treat such anomalies (such as audits), appear to limit the analysis of the anomalies detected to non-compliance with procedures, without questioning the underlying reasons for the non-compliance, and ignoring organizational and human dimensions. On the other hand, fragmentation of the safety management system, results in the accumulation of separate databases full of data which are not mutually linked and integrated. This is reinforced by a mechanism of information filtering, which blocks the site's capacity to make sense of the anomalies detected, and perceive the anticipatory/predictive power they possess.

-Finally a limited and rigid risk perception, rooted in the Rex tools and the frameworks of analysis which the individuals and the organization have, present a brake on any double-loop learning.

The third part deals with final synthesis of the results.

PART 3: DISCUSSION AND CONCLUSION

6. Final synthesis

6.1 Introduction

The second and third chapters of this thesis addressed methodological and theoretical issues. They were structured around the issue of weak signals as a vector of organizational learning. Chapters four and five presented the results of two case studies, particularly dealing with the definition and roots of weak signals of accidents.

This last chapter entitled "Final synthesis" is intended to summarize the overall results of this research. We will address the following three themes:

1. Comparison

Initially, as was proposed in the Methodology chapter, we compare the results of the two case studies at three levels of analysis.

First level, the definition of weak signals. Three categories of weak signals have emerged from the case studies: technical weak signals, weak signals related to "work coordination" and weak signals relating to “underestimation of risk”. This chapter's primary objective is to present these three categories of weak signals and to identify their common characteristics.

Second level, the roots of weak signals: for these three categories of weak signals, we have identified three activities of normal operations in which they appear to be rooted:

a) Technical weak signals rooted in the system of technical failures management,

b) Weak signals concerning “work coordination” rooted in the management of sub-contracting and the coordination of operations,

c) Weak signals concerning 'underestimation of risk" rooted in the proactive and reactive tools and processes for risk analysis conducted by both sites.

These three normal operations facilitate processing of known categories of data, but tend to discard categories of unknown or unexpected data, especially the three categories of weak signals presented above. We will compare the two cases to show whether these same activities give rise to the three categories of weak signals in both the ACIO and EDIA sites. We do not pretend that these three types are in any way an exhaustive categorization of weak signals, since they are only based on two case studies.

Third level, organizational factors: finally, we have identified common organizational factors in both sites underlying the weaknesses in the normal operations, and, as a result of these organizational characteristics, have identified that both sites are restricted to organizational single loop learning and do not achieve organizational double loop learning. The purpose of this chapter is to compare these organizational characteristics and discuss whether they have a generic characteristic (i.e. whether they might be found in other industries).

2. Recommendations:

In a second step, we have tried to create as strong a bridge as possible from a sociological description of the EDIA and ACIO sites on the one hand, focusing on organizational factors blocking, filtering and amplifying weak signals, and, on the other hand, a more practical proposal, to open up avenues for the improved treatment of weak signals. Based on the work of Hale (2003) and Koornneef (2000), the second part of this chapter will be devoted to recommendations whose objective is to assist and support sites in the establishment of a method of risk control which may promote better treatment of weak signals. This is accompanied by the presentation of a first rough concept of a practical guide entitled "Taking into account the weak signals in risk control", which is meant for industrial sites.

3. Evaluation of action research

Finally, the last part will deal with the evaluation of the action research conducted for achieving my thesis. This has been a mirror for the companies, but also for the researcher. We will stress the contributions, but also the limits of action research as part of this thesis.

6.2 Case-study results compared

The importance of carrying out two case studies lies in the comparison of the results. This method allows us to reveal the differences and therefore the specifics of the two cases, but also to reveal their similarities. Our objective is not to generalize these results too broadly, because they are based on only two specific cases, but just to define common features to the EDIA and ACIO sites, which, nonetheless, could serve as a starting point for other sites of similar complexity and hazard level to consider their own learning systems.

6.2.1 EDIA and ACIO safety managements: context of weak signals

6.2.1.1 Two levels in safety management

ACIO and EDIA safety management systems cover two aspects.

The first concerns tools for "internal" safety management. Prevention tools are designed to prevent or anticipate critical events upstream, and implement actions to correct dangerous situations before they turn into an accident sequence. Event analysis tools are applied after the event. They allow both sites to reconstruct an accident sequence, identify root causes and develop corrective and/or new preventive actions.

The second concerns tools related to "external” safety management and sharing of experience. The Rex forms, in both companies, are designed to share information and lessons learned from a critical event, both internally and with other sites of the same industry group. It is therefore a process of knowledge sharing. The major accident prevention policy applied on both sites is intended to maintain plant and staff safety on site but also outside the site (as defined by the major accident definition, see section 4.4.1.2.3). The information related to this is disseminated to the sites but also to local administrative authorities (Direction Regionale de l’Industrie, de la Recherche et de l’Environnement).

Tool	ACIO	EDIA
Internal tools for prevention (proactive)	-Behaviour audit -Prevention plan Audit	-Workplace audit -Constats d’Anomalies Traitées (CATs) -Scheduled General Inspections (SGIs) -Quality audits
Internal tools for event analysis (reactive)	-Accident meeting -Fault tree analysis -HSC -External expert -Rex notice	-EVEN+ -Accident reconstruction -Event analysis - Fault tree analysis - HSC - Rex notice
External: Rex tools (reactive) **External: Major accidents policy (proactive)**	Rex forms Risk analysis and bowtie method	Rex forms Risk analysis and bowtie method

Table 5: Summary of risk control tools used on the EDIA and ACIO sites and studied in the PhD research.

EDIA and ACIO would appear to have designed tools that cover the broad spectrum of risks, from proactive detection to reactive event analysis (“weak signals” Rex and “critical events" Rex according to Gauthey, 2005). Despite the wealth and use of these tools, we have shown that there are many limitations in the safety management systems implemented by both sites.

6.2.1.2 Rex process limitations

6.2.1.2.1 Formalized Rex process

Firstly, the two case studies agree on the following specific operating procedure for the Rex process (figure 30):

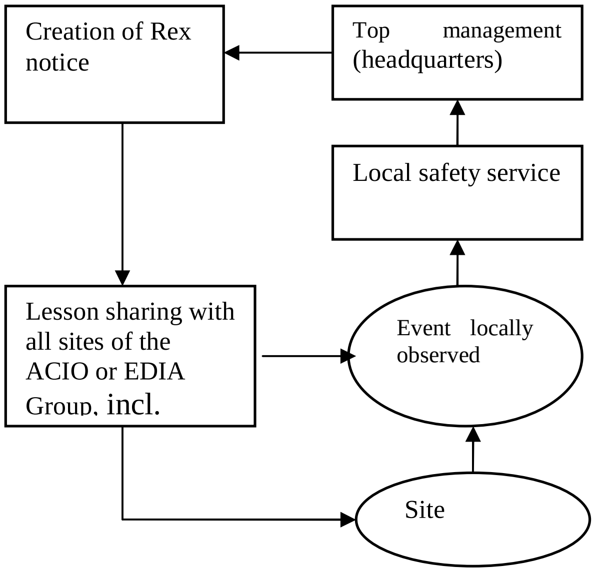

Figure 30: ACIO and EDIA Rex process functioning.

The Rex process follows three stages:

-Locally, the detection and notification of an event,

-Centrally: event analysis ensured by experts who create the Rex notice,

-Distribution of the form so that lessons learned are shared.

The Rex forms ensure dissemination of generic or shareable lessons occurring in specific contexts. The EDIA and ACIO sites implemented their Rex processes as a result of the 10th May, 2000 regulation requiring High Level Seveso sites to implement Safety Management Systems and especially Rex processes. As a result of this, Rex is a common tool, meaning that all sites of EDIA and ACIO Groups have to apply the same procedure. This would partly explain what Gilbert (1999) and Bourrier (2001) have called the strong formalization of Rex.

Secondly, observations showed that the Rex process was not a global approach but only one tool as part of the safety management system. As it appears to be applied on the sites, the Rex process would seem to be used more as a reactive tool for event analysis than as a proactive one, applied upstream of critical events. Based on our observations presented in chapters four and five, we therefore agree with Gilbert’s thesis (1999), who observed Rex processes essentially based on "critical events", and that of Gauthey (2005) who in turn noted a difficulty, for industrial sites, to apply what he calls a "weak signals" Rex, which we interpret as a proactive process. However, these limitations must be moderated, because we observed a range of complementary learning tools, locally developed by EDIA and ACIO.

6.2.1.2.2 Complementary tools

To complement the reactive nature of their Rex, both sites have implemented proactive tools (see table 5). However, these tools also seem to generate or reinforce two problems. On the one hand, they do not appear to escape the problem of formalization and proceduralisation. Both cases studies emphasized that the application of the tools such as anomalies reporting was used more to demonstrate compliance with procedures or formal requirements (e.g. ISRS on the EDIA site) than to learn significant (unexpected) lessons from the anomalies detected. We have also highlighted that each company has a large number of tools dedicated to anomaly reporting (whether technical, behavioural, or quality) which generate an accumulation of data in a fragmented set of databases.

The use of the rather reactive Rex tool, together with the more proactive anomaly reporting tools, does not, of itself, necessarily guarantee the implementation of a coherent global (proactive and reactive) safety management system for the prevention of accidents. We have uncovered two factors in particular that may be responsible:

-A difficulty in linking the data from the different tools so as to be able to integrate them

-A difficulty in making sense of the data, that is to say, to identify the patterns of occurrence of precursors and of recurrence of anomalies or of significant events in the database, and the underlying causes of these recurrences and events.

In this context of the relative failure of the Rex processes, characterized by formalism and reactivity, we have seen in chapters four and five that information, however relevant to the accident analysis occurring in ACIO and EDIA sites, got ignored or discarded.

6.2.2 First and second levels of analysis: the roots of weak signals

Based on the surveys conducted on the ACIO and EDIA sites, we identified three categories of weak signals:

-Technical weak signals: the persistence of latent, recurrent technical failures whose causes are neither fully identified nor analyzed in depth,

-Weak signals related to work collaboration (particularly in contracting work) which indicate the development of informal practices to get around inadequacies in the formal arrangements, but which may not be identified as threats to safety, and for which corrective and preventive actions measures are therefore not implemented,

-Weak signals relating to "risk perception", i.e. an underestimation of certain types of risks not identified and dealt with in proactive risk analysis or reactive event analysis.

These categories arose from the comparison of the results of the two cases and highlighting of similarities between their weak signals categories. The next section will present their common characteristics in detail.

6.2.2.1. Weak signal categories: case study contributions, first level

6.2.2.1.1. Technical weak signals

Characteristics

Technical weak signal are defined by their repetition and persistent weakness. They are "latent" that is to say they are "*diffuse, less visible, but can occur at any moment*" (Larousse dictionary, 2010). The anomalies in filter cartridges (ACIO, accident 2) and failure of maintenance of the roof of the silo (ACIO, accident 3) were identified on several occasions before the respective accidents. Despite repeated maintenance operations, these anomalies kept occurring and being detected. Retrospectively, and especially during the stage of data analysis and thesis writing, I realized that the limescale blockages detected in the steam lines (EDIA accident) could also have been defined as a technical weak signal. In fact, this anomaly had been detected several times before the maintenance campaign during which the EDIA accident occurred, but remained unresolved. Given the late realization of this factor as a potential issue, we did not have the opportunity to go back to the site and check the relevance of this hypothesis, but we make the assumption that the EDIA site also did not seem to have learned from previous technical problems which, finally, led to the new maintenance campaign and the EDIA accident.

These persistent technical anomalies were identified retrospectively (through event analyses) which were relevant and essential information in understanding the accident sequences. Yet these were not corrected before the accidents happened.

We have shown in the case studies chapters that the management systems for technical anomalies largely treated only the known and expected categories of data and then only in a "simple" way, that is to say without looking for the underlying causes of their eventual repetition. Instead of treating and solving all types of anomalies, including unexpected ones, this activity of normal operation left those unexpected and underlying signals weak (at least those identified in this research).

Roots of technical weak signals: the anomaly management system

Firstly, some signals remained latent because they did not benefit from deeper analysis. The sites appeared to be satisfied with a superficial analysis and (continuing) correction without questioning the origins or causes underlying the recurrence of these anomalies. Not only did the system not encourage the extraction and identification of patterns of recurrence with a potential to warn of future accidents, but in addition it did not take such underlying factors into account, which played a part in the persistence of the anomalies.

Secondly, and this is a consequence of previous point, the effectiveness of the preventive and corrective maintenance performed on the equipment was not questioned. We recall that removal of scale from the steam lines on the EDIA site was performed a number of times before the accident that we analyzed, and the filter cartridges in the oxygen line (ACIO, accident 2) had to be replaced many times. This had happened without triggering the question whether this maintenance was the best way of dealing with the problem, or whether a deeper analysis would show problems such as the design of the equipment or of the maintenance methods.

To conclude, these two weaknesses, in the analysis of recurrent failures and the failure to question the relative ineffectiveness of some maintenance operations, underlie the persistently weak technical signals.

6.2.2.1.2 Weak signals related to the work coordination

The EDIA accident and ACIO accident 1 raised the issue of coordination between the employees of the subcontractors and those of the companies during maintenance work.

**** Characteristics: two opposing views of work organization***

Firstly, the operational completion of maintenance work is characterized by a number of interfaces between the company operators (ACIO and EDIA) and the sub-contractors, together with a strong interdependence and continuum of tasks between them and an atmosphere of pressure due to the time within which work must be carried out (see sections 4.4.2.1.2 and 5.4.3.1.1). Secondly the work has a strong bureaucratic or administrative element. The more the work requires a high coactivity (many contractors working together), the more its organization is complex and segmented, which does not seem adapted to the operational organization (see above). To overcome these difficulties of allocation of tasks, the EDIA and ACIO sites both use a method of work coordination characterized by a centralization of the main steps (upstream planning, the development of prevention plans, allocation of work permits, management of change/coordination meetings, etc.), whether those are normal practice (ACIO accident 1), or should have been in place (to prevent the EDIA accident). In a context of high work pressure, where to take into account any change in the initial organization of work requires a response which is both prompt and appropriate to the operational constraints, such a long-winded and formal administrative organization does not always seem appropriate. This issue will be developed more in section 6.2.3.1.

****Roots of the weak signal: contractor's management***

The prevention plan and the coordination meeting were considered, in the context of this research, as two procedures to detect anomalies and predict more precisely the risks associated with the coactivity, but also to resolve them.

We showed that the centralized administrative organization of work underlying these two procedures could produce an inappropriate response to the conduct of operations that would require, instead, a local and coordinated response. To overcome this difficulty, operators seemed to adapt or bypass the formal procedures to their constraints by creating and maintaining informal practices that got the work progressed, but complied with neither the administrative procedure of the coordination meeting nor the requirement to develop a new risk analysis related to coactivity. These findings are in line with the work of many sociologists who have studied work organization and specifically investigated the possibility for actors in an organization to apply formal rules while performing their duties. We follow Bourrier's proposal (1999) which invites the reader to consider high risk organizations just the same as "classic" organizations, that is to say, doomed to encounter the same obstacles, the same problems, and, what concerns us here, the same bargaining between actors to adapt rules to operational constraints. This issue will be discussed further in section 6.2.3.1 of this chapter.

6.2.2.1.3 Weak signals relating to the underestimation of risks

****Characteristics***

Finally, chapters 4 and 5 dealt with a third class of weak signals, the underestimation of risks. We found some risks that were poorly or inadequately evaluated upstream, e.g. the quality of risk analysis when designing a section of the plant (such as the silo in the ACIO accident 3, for example), but also during event analysis (the importance of retention of and compliance with the permit to work in ACIO accident 1). These risks, although present were not taken into account and hence persisted and were no longer considered exceptional, becoming acceptable for all stakeholders (operators and managers) in a form of normalization of deviance (Vaughan, 1996). Although these risks were, in some cases, identified retrospectively after the accidents, we showed that neither the analysis nor the recommendations had addressed these risks deeply enough.

Two causes can be identified:

-A weakness in the risk analysis, in particular in the analysis methods applied, but also in distributing by training and information the active knowledge about risks such as steam or oxygen so that they would be present in those concerned

-Resistance to or difficulty in thinking the "unthinkable" – a lack of openness to the unexpected. The work of Roux-Dufort (2000) and Turner & Pidgeon (1997) make sense here. This difficulty can be a blocking factor, and result in ignoring some signals.

It was only after a critical event (in the case of ACIO accidents 2 and 3) that changes have been made to integrate the newly reappraised risks found in the accident analyses.

6.2.2.1.4 The first part of a definition of weak signals

Empirical data and literature now allow us to define weak signals relevant to an accident. They are qualitative, ambiguous and/or fragmented information (Mével, 2004, 2006) so that their threat to safety is neither clear nor direct (Vaughan, 1996). They are characterized by ambivalence, to the extent that they are hardly noticeable (Blanco & Lesca, 2002), but they offer the potential of anticipation of future accidents (Ansoff & McDonnell, 1990). Besides, weak signals do not fit the categories in current classification systems (or risk perception frameworks) or may seem to threaten existing views of what is important for the operation of risk controls.

These signals, although they reveal specific characteristics, become or stay weak in the context in which they exist. The next section deals with this second part of the weak signals definition.

6.2.2.2 Normal functioning: the root of weak signals in three activities of safety management, second level

For each of the three categories of weak signals, a normal activity was defined as the mark or root of that specific category. Thus, the root of technical weak signals was found in the system of management of technical failures, the root of the "work coordination" weak signals in the relative inadequacy of the bureaucratic organization of coordination of contract work, and the root of the "risk perception" weak signals in limits to the proactive and reactive analyses of risks and the distribution of that information to those needing it..

The importance of this categorization is twofold. First, it allows us to observe the influence of normal operation on the persistent weakness of the signals identified above. The intrinsic characteristics described reveal defects that facilitate the persistence of the three categories of weak signals. This categorization also reveals a relative compartmentalization and consequently a lack of interconnection between these three activities. We observed indeed a lack of linking of data on technical anomalies with other sources of data on safety (e.g. audits, but also data on critical events and major accidents). It seems necessary to make these connections in order to ensure effective risk control in ACIO and EDIA.

How are safety management weaknesses rooted in the organizations we investigated?

6.2.3 Third level: the organizational roots of weak signals

6.2.3.1 Organizational complexity: obstacle to coordination

In the literature review chapter, organizational complexity was considered from two angles. We suggested, on the one hand, that organizational complexity could lead to compartmentalization of the services or departments of an organization (Pierlot & al, 2006), making transmission of information difficult (particularly on safety). On the other hand, the complexity of professional relationships, due to the multiplication of relationships within the organization (Turner & Pidgeon, 1997), can amplify communication failures, and be seen as a new source of risk. We chose to treat more specifically the disjunction between the staff and line areas, a hypothesis tested in chapters four and five.

The following sections are intended to highlight the impact that organizational complexity can have on the "work coordination" and “underestimation of risks” weak signals.

6.2.3.1.1 Centralization of control vs. self-regulation, autonomy or informal regulation

The contrast between staff and line areas, described in section 6.2.2.1.2 remains a hypothesis. It links to the work of sociologists who have studied rules (routines) and the practice of bypassing or re-interpreting rules. These works were not considered in the literature review because their relevance was only clear after conducting cases studies.

The opposition between the written rules, established by safety staff, and their reinterpretation by line operators recalls the distinction between ‘control regulation’ and ‘self-regulation’ (or autonomous regulation) proposed by Reynaud (2004), who wrote: *"In a social system which is complex and is tending to become more so, the effort to address problems through central control is not effective because it increases the distance between the location of the problem and the place of the solution (and, in our language, between regulation and self-regulatory control (...). Regulatory control strengthens and develops itself, and there is a centralization effect. This increases centralization and exacerbates its inefficiency. It is thus a vicious circle*" (p. 226-227).

Prescribed rules, as we showed particularly in chapter five, may be ineffective. To address problems encountered in field operations, operators tend to interpret formal rules and adapt them to their operational constraints (that is to say, the material constraints of time and coordination between different actors involved in maintenance work). Crozier (1963) shows precisely why and under what conditions certain provided, written or "impersonal" rules in his terminology may be incomplete. He cites the famous case study of Monopole[50] and deals more particularly with the power machinery maintenance operators have: "*Machine stoppages are the only major event that cannot be predicted in advance and for which we have failed to impose mandatory impersonal rules (...) Such rules do not allow us to determine whether a failure will occur and how long the repair will take. There is a great contrast between the rigidity of rules that prescribe the smallest detailed measures to take, and the complete uncertainty prevailing in the technical domain* "(p. 130).

[50] Monopole is the name M. Crozier gave to SEITA (Factory of cigarettes). This case study is famous (at least in France) because it illustrated well his theory of “strategic analysis” in the organizations.

In the case of the EDIA and ACIO accidents, the prescribed rules that interest us, e.g. the coordination meeting, turn out in some cases to be impractical. This coordination meeting is a meta-rule intended to predict and anticipate the unpredictable, namely unexpected changes, in an ideal way disconnected from the context of the actual work of operators. However, the practical limitations of reality described in the case study show that the pure application of the rule is difficult and that human intervention to bypass it is sometimes necessary. The operators can thus be seen as actors capable of surveying the limits of a rule, but also as actors able to exercise control and direct intervention in the technical system (Bourrier, 1999). The question then is whether they are competent and perspicacious enough to make this informal intervention work not only rapidly but also safely. In the case of the accidents studied, this was not the case.

6.2.3.1.2 Effects on weak signals

In the domain of risk, two viewpoints are often mentioned. Either man (the operator) is seen as a source of error, that is to say that interpretation/adaptation of a rule is perceived as an error, failure or violation of the rule, or the operator is seen as a source of reliability, because, thanks to his ability to take initiatives, he is able to maintain the good functioning of the organization exactly by that adaptation, and can, in some cases, retrieve errors and hence avoid accidents (Leplat & Terssac, 1990).

In both cases, the organization of work and particularly the disjunction between the staff who design and prescribe the rule, and the operational line, who have to apply these rules, gives rise to the needs or even necessity to reinterpret them. The organization thus creates necessary violations, which may be tolerated, or even normalized by management, rather than being made explicit and assessed for their incorporation into the formal rules, or attempts at their suppression. This relies on an implicit functioning, aware of the incompleteness of the prescribed rules it produces. The need to bypass a rule or to adapt it to the constraints of work was discussed in the literature review through the work of Grabowski and al. (2009) and Leplat & Terssac (1990). They rightly state that these interpretations of rules become necessary when the organization fails to provide operators sufficiently with the conditions necessary for completing their work, and especially the necessary resources to revise rules that cannot be formally applied.

These “unofficial” practices have two consequences. On the one hand, they emerge from practices that may threaten safety, but would also keep the business running. It is not that the procedure (based on the formal rule) prevents continuity of the work, but the literal application of it would slow down or even break the (rhythm of the) completion of the work On the other hand, these practices remain inconspicuous for two reasons: they seem not to be detected or observed as threats to safety and are, in some cases, tolerated by the hierarchy, who turn a blind eye. These practices become, therefore, normalized as new standards of performance, and legitimate in the eyes of the operational actors.

In this context, we put forward the idea that the organizational fragmentation observed at the EDIA and ACIO sites would encourage or make necessary such rule reinterpretation and would lead to the persistent weakness of the "work coordination" weak signals which affect safety, as has been shown in this thesis. Fragmentation is necessary in a complex organization: the division into departments and expertise groups is necessary to organize work and business. Our project is not to judge the effectiveness of this aspect of an organization, but to identify the impact of such departmentalization on the treatment of weak signals. The construction of such subcultures, sometimes autonomous, then favors the emergence of coordination difficulties and extra efforts have to be put in to bridge these communication gaps.

6.2.3.2 Safety management fragmentation

Organizational complexity has an effect on safety management. We observed fragmentation at two levels:

- -The control of risks is envisaged at three levels of severity - anomalies, critical events and major accidents, operated by different people/services
- -There is a fragmentation of databases which manage the data related to these three levels of severity

6.2.3.2.1 Three levels of severity

The safety management systems of both the EDIA and ACIO sites are based on Bird’s Pyramid. As a result, both sites believe that the detection and correction of anomalies, whether technical, behavioural, or quality (respect of procedures and respect for the quality of the product) can anticipate and prevent potential incidents/critical events and major accidents. They also assume, and that is Bird's thesis, that the causes of anomalies, significant events and major accidents are similar, and therefore there is a logical and linear link between the three levels of severity. However, in practice in both sites, each level of the pyramid is managed by a different (or autonomous) management/service, which implies that the sites consider in practice that the phenomena at each risk level are independent, and for which distinct causes can be identified.

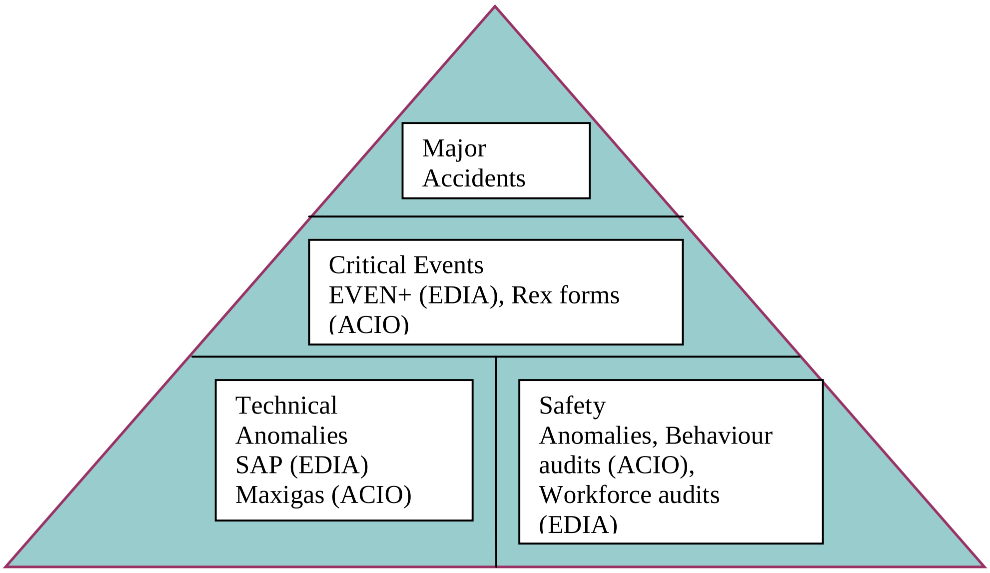

Figure 31: Safety management fragmentation, EDIA and ACIO sites

Figure 31 illustrates a fragmented vision of safety management at the three levels, and for each level a compartmentalization of resources allocated for data management (different departments responsible for managing the data). This seems paradoxical. The model of the Bird's Pyramid should allow both sites to view or represent an overall integrated risk control. But this fragmentation shows a clear separation among the three risk levels and between the databases on safety, preventing the EDIA and ACIO sites from establishing a comprehensive and integrated risk management.

6.2.3.2.2. Rethinking the Bird Pyramid

The work of Hale (2001) provides a critical look at the Pyramid of Bird. The fragmentation of safety management into risk levels is relevant in his view to distinguish exactly those near misses or deviations which that may lead a major event, from those anomalies without any potential major consequences.

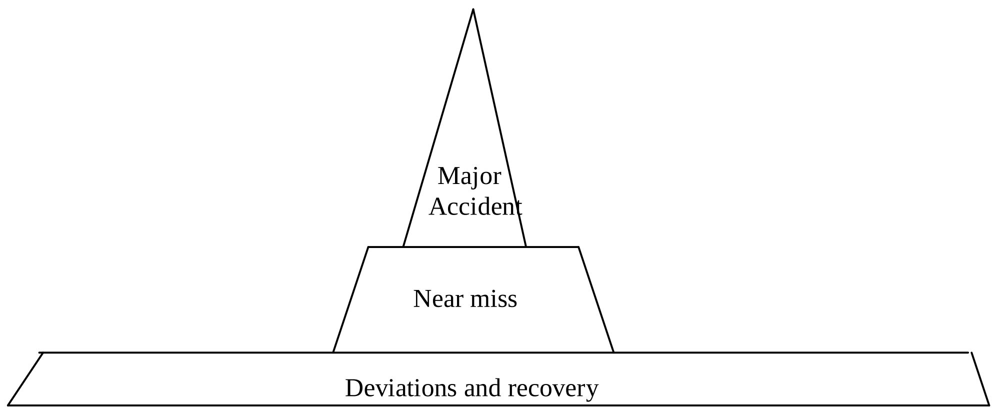

Figure 32: Pyramid of the prevention of major accidents, (Hale, 2001)

The pyramid amended by Hale (Figure 32) proposes to consider the prevention of major accidents in terms of scenarios. According to Hale, any given scenario is built on the same logic: the emergence of signals or indicators of deviation, action or failure of safety barriers, leading eventually to a central event (loss of control of the hazard) and the consequences of this event. Within one scenario, if at least one of the successive barriers is successful there will only be a recoverable deviation, a near miss or an event with minor consequences. Within this one scenario the logic of Bird works. However, contrary to what the Bird Pyramid suggests, as it is applied in both sites, not all anomalies can lead to major events if left uncorrected. Detection and correction of the risks of slips, trips and falls will not provide relevant data to prevent the risk of toxic releases or fire. Such minor events, although detected upstream, will not help to prevent major accidents. Identifying accident scenarios and clearly understanding their origins and development can assist companies to define relevant warning signs within the accident scenario, and to put adequate detection and treatment tools for them in place. Hence the data aggregation and analysis tools available to the company need to be deployed within scenarios to couple the precursor (weak) signals to their relevant near misses, critical events and major accidents.

6.2.3.3 Information filtering process

Within each level of severity identified in figure 31 (or 32), a process of filtering of information has been described in chapters four and five. Through the chain of information transmission (detection, interpretation, transmission and reception) three types of filters – related to tools, cognitive and organizational factors - have been found to be involved.

Filters play two roles. On the one hand, they amplify “simple” data. These data are characteristic of known risks, predefined and integrated in the information management system.For these expected signals simple analysis and treatment have been implemented and by and large they work well and need to be retained. On the other hand, the filters discard any data that do not meet the criteria for detection and interpretation built into the categorization. These data may be complex because they refer to less known or unexpected risks or scenarios, or reveal underlying organizational dysfunctions related to safety which are not catered for in the classifications. In this way the classification systems make or keep these signals weak.

6.2.3.4 Single loop learning as a result of organizational characteristics

6.2.3.4.1 Formation and persistence of weak signals

Figure 33 shows to what extent the organization may create the conditions for organizational single-loop learning (level 4). By filtering out information related to safety, the organization does not grasp the opportunity to question levels two and three, failures in which could be revealed by the weak signals. The system is self-reinforcing and perpetuates the limitation to organizational single-loop learning.

Figure 33 summarizes the ideas we have developed so far. The first level focuses on the persistent weakness of signals (anticipatory information but discarded). The distinction between the three types of weak signals is generated by the safety management fragmentation (second level) which compartmentalizes these three activities, as well as the processing of the simple and complex data. Fragmentation is rooted in the very structure of the organization (third level) which distinguishes the operational (line - local) and the administrative (staff - central) aspects of work organization (particularly in the management of maintenance operations). The organizational fragmentation has a major impact: a desynchronization of work that is to say a break in the continuum of the timeline and the realization of the work.

6.2.3.4.2 Second part of the definition of weak signals accident

The study of abnormal operation (the accident process) and normal operation allowed us to define the second dimension of weak signals. Some signals become and remain weak because of organizational factors -fragmentation and filtering of information- which block the ability of actors making up the organization in their task of making sense of these signals and learning wjhich remains at the first level.

The objective of the next section is to present a method for the consideration and processing of weak signals, and the passage from organizational single loop learning to organizational double loop learning.

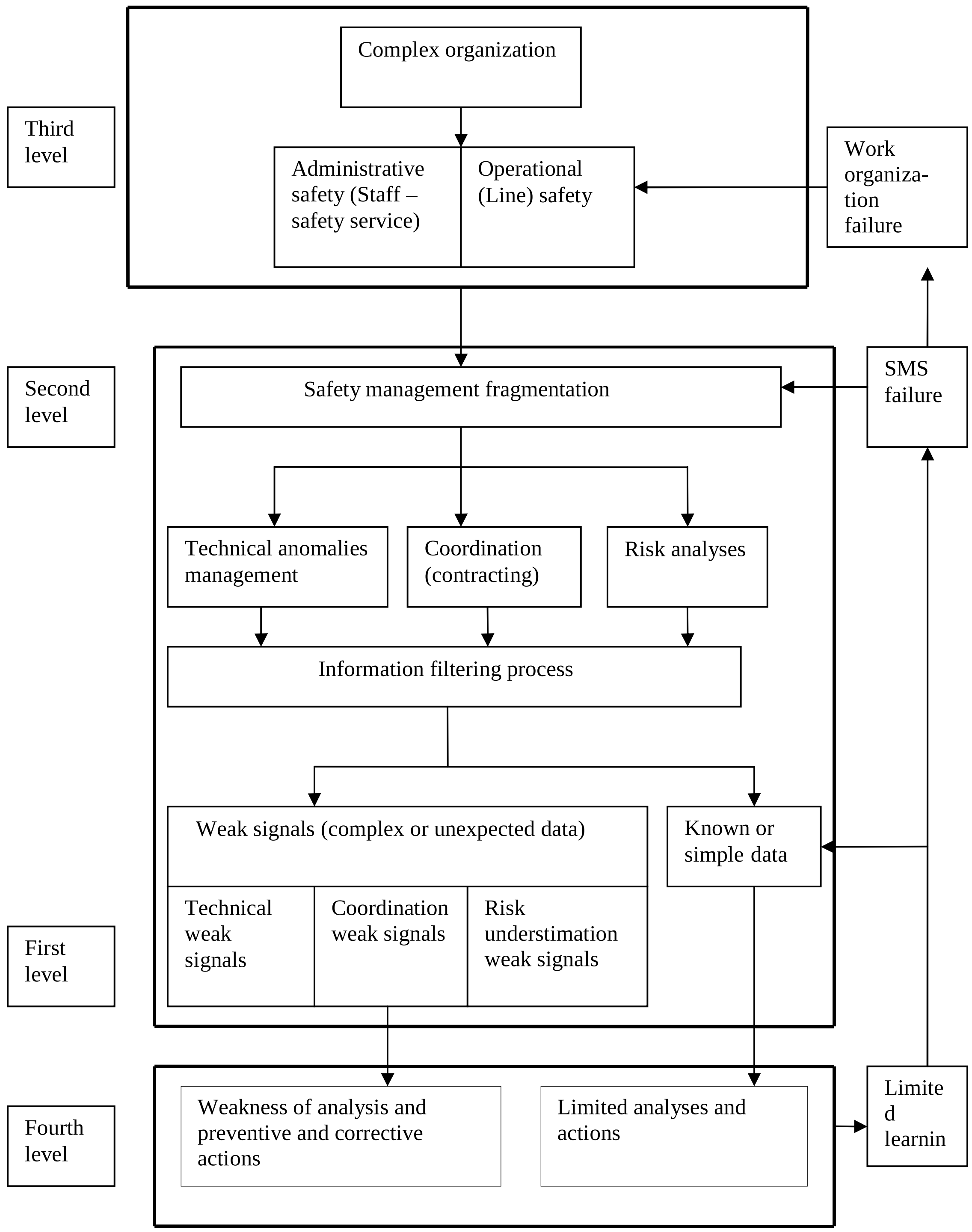

Figure 33: Process of persistence of weak signals (derived from the results of this research)

6.3 Weak signals treatment: implementation of a global risk control approach

In this thesis, we consider the Delft model (presented in the literature review, section 2.3.3) as a relevant approach for dealing with weak signals. First, this model has the advantage of offering an integrated risk control system which would overcome two main weaknesses so far identified: the fragmentation of safety management and the process of filtering information. Then, this model includes, in its principles and functions, organizational double-loop learning, and makes it not an annex but a central feature, ensuring a constant review and improvement of safety management and therefore its consolidation. Finally, it is a prescriptive approach whose strength is to indicate the functions and resources necessary for the implementation of this method. Thus, it plays a role as a framework guiding organizations, which can then operationalize the functions to suit their own nature, structure and culture. This method does not aim to add a set of tools to those which are already in use, but to provide a critical look at their effectiveness and assist sites in their review and optimization. We put this method forward as a proposal to resolve a range of problems found in the two sites, but we have been unable to test it out in practice because of lack of time within this project.

We will first take four principles of the Delft model[51] - safety barriers, resources scenario building, and learning process - and show that risk control of the ACIO and EDIA sites does not respond at all, or only partially, to the principles that constitute the model, which explains the difficulty of handling weak signals. In order to contribute to organizational reliability, we will then propose recommendations to meet the challenges of weak signals.

6.3.1 Maintaining a good level of safety

It seems difficult to define a starting point for recommendations because we believe that the issue of weak signals, and particularly their integration in safety management, is a complex process and it occurs at different levels of the system (see figure 33). But for purposes of clarity, we propose to begin by the first and second principles.

6.3.1.1 Safety barriers: first principle

Safety barriers are defined as means/defenses to prevent and control major hazards. Hale (2003) stresses that barriers can be physical, process instrumentation and control, safety barriers, and human behaviour manifest in works systems. Safety barriers may be physical or procedural or

[51] We will set out only the principles of the Delft method which we judge relevant to explain the findings of the thesis.

both. The main interest of safety barriers lies, according to us, in the way they are used and included in safety management to facilitate and ensure safety on sites.

A number of ACIO and EDIA organizational characteristics have been shown to represent major obstacles to the treatment of the weak signals categories we have identified.

Besides a scenario approach, we believe in the importance of creating organizational conditions promoting weak signals treatment. Based on the Delft model, effective safety barriers, be they technical, procedural or organizational, and the availability of resources for the functioning of these barriers, are essential to maintaining safety.

The following discussion does not concern the application of barriers and resources in the entire organization, although we believe the principles should be applied across the organization. However we take as example a specific issue that we particularly developed in this research: coordination of maintenance work.

6.3.1.2 “Delivery systems”: coordination, clarity of procedures and competence, second principle

Let us briefly recall that, in the context of the completion of maintenance work, we found that the staff organization allocated relatively inadequate or inappropriate resources to operators for the implementation or revision of the initial organization of work (particularly in respect of the coordination meeting). The tasks are greatly decentralized, whilst the mechanism of the coordination meeting is complex and centralized. The problems caused by this generate a local response, namely the creation of persistent deviant practices. Because they were not detected or not seen as threats to safety, these practices still continue to exist (level 3 in figure 33). We conclude that the problem of work coordination was rooted in the organizational fragmentation.

Following these findings, several recommendations can be submitted. Firstly, from the phase of planning and design of the work to be done and of the call for intervention by the subcontractors, the relevance and effectiveness of job allocation and segmentation should be explicitly thought through. The EDIA accident showed that to complete maintenance operations, even the simple splitting of tasks into two work permits could be a factor in work complexification and therefore a source of risk. Thus, it is a matter of revising the way in which work organization is managed – whether it is good to have several subcontractors to perform a simple operation - and also of revising the operational organization of work, that is to say, the allocation of several work permits according to this division of tasks. Then, the clarity and effectiveness of procedures seem a necessary focus of attention and improvement, especially equipment handling (the procedure for isolation and making safe was incomplete or even non-existent and had to be written after the EDIA accident) but also the clarity of the rule describing the way in which the authority of different actor's was allocated and coordinated. Finally, skills and knowledge of operators (for example in relation to steam and oxygen risks) play a central role.

If we refer to the Delft method, we find that this identifies communication, procedures and competence as three essential delivery systems to maintain the good functioning of either physical barriers –e.g. the locking-off of the isolation valve - and organizational barriers, e.g. work permit allocation. Incomplete procedures, poor coordination, or unrevised skills or knowledge lead to the partial effectiveness of safety barriers and represent inadequate resources to guarantee that effectiveness. Being explicit about the barriers that need to be in place to control the risks, and about the resources needed to ensure their continued good functioning would make obvious the place to look for the currently persistently weak signals related to "work coordination" and "under-estimation of risks.

6.3.1.2.1 Availability: ensuring decentralization of decisions

Availability is defined as a delivery system by Hale (2003) in the Delft model as: "*The allocation of skilled people and equipment needed for critical operations that must be available when operations are conducted*" (Hale, 2003, p. 25).

Poor availability was indeed one of the failures we identified in the EDIA accident and ACIO accident 1. Not only the ongoing operations were not supervised, but this had led to a necessary violation of the coordination meeting procedure to ensure that operations could function. More availability of supervision would enable two things. On the one hand, it would provide the human resources to organize and validate a coordination meeting (specifically, the supervisor would have the authority to sign and authorize the change of the prevention plan). On the other hand, this procedure could be performed more locally, that is to say on the work site, which would make it more decentralized and thus more suited to respond locally to unforeseen changes in the maintenance work.

The traditional opposition between the design (formulation) and execution of a rule (or procedure) can then be discussed again as proposed by Bourrier (1999). She points out that written (or formal) rules need correction, and they need feeding with the experience of the operators who can tinker with the rule in order to revise it so that it is appropriate to operations and does not always have to be violated. This also recognizes operators' skills in their ability to recover from dangerous situations. As a response to the organizational complexity and centralization of decision making, Rijpma (1997) believes that high reliability organizations are characterized, among other things, by their ability to decentralize decision making. This principle allows them both to solve problems (technical anomalies or changes in work) when and where they are detected (because decision making centers are located closer to operational activities) but also to promote autonomy and recognition of operators' skills to respond to complex situations.

Given the above, the availability of supervisory staff seems important to promote the decentralization of some rule (re)design and thus reduce the gap between the formal and informal (or between the staff (administrative) and line (operational) management of maintenance works). This would contribute to the resolution of the weak signals related to "work coordination".

The actions we propose to improve the delivery systems focus on the organizational level of maintenance (although applicable in principle across other aspects of the work of the two companies) and are designed to make explicit the link between resources and barriers to keep risk control functioning.

Can these principles, formulated in the form of recommendations, have an effect on the quality of organizational learning, which operates at a meta-level?

6.3.1.2.2 Commitment: rule violation or rule ambiguity?

As Hale (2003) states, commitment – to safety - implies all means (rules, procedures) and resources (time, human resources, finances) used to resolve conflicts between safety and other objectives that may be contradictory. Commitment is not only required from operators (who are working on the shop floor) but also by line management and the organization in its entirety.

Thus, we believe that commitment is possible when operators and management understand and can apply rules and procedures and are not obliged, for other reasons (times pressures, production requirements) to exceed some rules in order to keep the system in functioning. However, we showed in section 6.2.3.1.1 that rules may, in some cases, not be applied because of their rigidity, complexity and the gaps they reveal between rules designers conceptions of reality and the real needs of operators. As a consequence, we believe that the organization may build itself the conditions for violating the rules because of the difficulty to apply them, while still complying with safety requirements (see ACIO accident 1 for example).

6.3.1.3. From a systematic logic to scenario reasoning: third principle

An organization must be able to identify potential accident scenarios, to cover the risks identified and discussed previously. The work of Hale (2003) provides relevant insights to this issue. In the WORM project, the research team modeled 51 scenarios, clustered according to the following themes, which covered all serious and fatal accidents over a period of 4 years in the Netherlands – which we can take to be representative for any industrialized country:

-Falls (from heights [from different levels and objects] on stairs, or on the same level), and falling objects/structures,

-Contact (with tools, machines, vehicles, persons, animals, other objects, electricity, heat/cold, etc),

-Immersion (in liquids, collapsing trenches),

-Loss of containment (hazardous substances and atmospheres),

-Fire & explosion,

-Radiation,

-Extreme muscular exertion.

Risk identification and the construction or updating of scenarios are interdependent. The scenarios consist of the set of steps by which each type of hazard can escape from control and cause injury or other harm. They incorporate the barriers (or risk controls) – the second principle of the Delft model - which prevent those steps from occurring, indicating how the hazard type is (believed to be) controlled, and the organizational and procedural resources and processes – the third principle of the Delft model - which ensure that the barriers and risk controls are put and kept in place. They therefore offer a graphic indication of what factors are relevant to the good functioning of risk control and enable the currently weak signals (or failures of risk controls or the resources and processes ensuring they work) to be located and identified. On the one hand, we believe that the integration of less known scenarios and the factors important for their control in the preliminary risk analysis would encourage the organization firstly to review all existing scenarios and then to assess whether weak signals (at least the three categories we have defined in the first part of this chapter) are taken into account in them. On the other hand, the incorporation of the weak signals by connecting them to accident scenarios which have been previously built would assign them a function as indicators of deviation, emerging from the operational activity, and warning of threatening phenomena: the potential accident. In an accident prevention perspective, accident scenario building would give to weak signals all their anticipatory power.

For example, we have shown that identification of the repeated anomaly on the filter cartridges (ACIO, accident 2) could have alerted the site to a hardware or maintenance failure. The restored link between this latent technical anomaly and the accident sequence, included in the event analysis, could have enriched the risk analysis on equipment and on hardware maintenance principles. However, we should realize that this link is neither decisive nor systematic. It can be signal of a potential accident sequence, but not one which is 100% informative or reliable.

The case studies showed that neither site reasoned in terms of scenarios (or only for Major Hazard Safety Studies carried out by the responsible staff department). The fragmented accumulation of data and the lack of connections between those separate safety data sets were shown to block the sense-making related to weak signals. The importance of scenario thinking lies in the fact that it may help organizations to restore the links and the integration across all the data sources (technical, safety), following a clear objective of preventing the occurrence of potential accidents.

6.3.2. Organizational double loop learning

6.3.2.1 Fourth principle: effect of weak signal treatment on learning

The Delft method is based on the need to identify the risks that an organization is likely to face. It is a matter of developing an ability to implement tools but also organizational measures that not only detect known or expected data but also data hitherto little or not at all considered, namely the unknown or underestimated risks, which the company is currently not paying attention to (level 1, Figure 33). No management system can identify all hazards and scenarios perfectly in advance, so there has to be a learning loop to constantly update them. Hazard identification is, in the first instance recognition of the energies which are present in the organization and which can get out of control and damage plant, people or environment. This is not a particularly onerous task, since the manifestations of energies are limited in number. The hard part of this first principle is the recognition of the different ways in which these hazards can manifest themselves if control is lost, depending on which barriers are used to prevent the loss of control. This is the step of building scenarios.

6.3.2.1.1 « Mindfulness » or identification of new types of information

No organization can predict all its risks and scenarios correctly in advance, so it needs to be alert (or mindful) to new information which needs to be incorporated to change that picture. The concept of "mindfulness" proposed by Weick and al. (2007) is characterized by a willingness and ability to invent new "*provisions to make sense of unprecedented events, a more refined, more nuanced context and ways to deal with it* "(p. 2). One of the characteristics of High Reliability Organizations is the refusal to simplify; the authors supportive of the "mindfulness" concept, believe that "categories[52]" simplify and exclude a lot of data. They encourage a questioning of these categories in order to incorporate unprecedented or unexpected events. To observe information and signals means, we believe, to adopt a reflective attitude on the nature of the data collected and on the effectiveness of the detection and learning tools, to question whether the tools are achieving their objectives.

This resonates with Macrae's thesis (2007). He suggests the need, on the one hand, to recognize the rigidity of the existing analysis frameworks (cognitive, collective and organizational categories) used for treating data related to safety and, on the other hand, to open up these frames to allow the observation and processing of dissonant and unexpected data (Macrae, 2007). Such observation enriches detection. But to observe also means to select what will be seen as relevant data.

[52] The term "categories" remains vague. We shall define these in the context of communication as categories of observation and processing of safety data.

6.3.2.1.2 Making sense of weak signals: two steps

To promote a greater awareness of unexpected data implies a step of interpreting and making sense of the collected data in the learning system. It does not mean a need to increase the *amount* of data to be processed, nor to increase its systematic accumulation; as we have already identified this as a weakness in the two companies studied. On the contrary vigilance towards the weak signals alongside the expected and known signals is less a question of detection then of making sense (second hypothesis of the General Introduction) of complex and unexpected data.

In order to be relevant and integrated into safety management, these new data need to point to a threatening phenomenon (a potential accident). In other words, they must be interpreted as information with a power of anticipation. The two steps in sense-making proposed by Macrae (2007) and developed in chapter two seem relevant. This involves identifying the common factors behind repetitive data (decoding), and linking these data to a wider reference frame (recode). This would encourage the organization to move from observation of fragmented signals to the creation of information which would anticipate the occurrence of a hithertoe unsuspected accident.

6.3.2.1.3 Amplifying weak signals: an open communication scheme

The observation of these new data should lead to a revision of the analysis categories through which data are processed and transmitted. Revision of the communication scheme in order to take into account weak signals, requires the implementation of an open communication scheme (not closed) as was indicated by Turner & Pidgeon (1997). In that case, filters would not tend to discard these new data but to amplify them so that they would become stronger (level 1, figure 33) and change the picture of what risks are present and how they arise (the scenarios developed under the first principle).

We found that the EDIA and ACIO sites only partially fulfilled this principle of communication, because we showed that there was a strong filtering process which filtered out complex and unexpected data (weak signals) and paid attention to and integrated, on the contrary, only known and expected data. This first principle of open communication aims at reducing the distinction between these two types of data and increasing the quality of the data collected on safety.

One question remains unresolved: if the organization manages to observe the complex and unexpected data, how does it take them into account? Does it have the necessary resources to tackle them and give them meaning to close the learning loop?

Level 4 (see figure 33) indicates that the sort of failures of safety management and of organization which we have described tend to limit learning to a single-loop, aimed at correcting deviations and returning things to the status quo, rather than making improvements by questioning the effectiveness of current methods. The fourth principle of the Delft method, which is related to the purpose of this research, is precisely to activate the switch to double-loop learning, which triggers that questioning and improvement.

In this research, we focus specifically on the lessons that an organization derives from incidents and accidents. Hale (2003) wrote: "*Feedback (Rex) … can either indicate defects in the selection of barriers and control measures or indicate risks not known or not identified in the preliminary risk analysis* "(p. 29). Feedback has two objectives: learning from accidents (about prevention) and learning about the effectiveness of the feedback (Rex) process itself. The ACIO and EDIA case studies led us to a critical vision of their Rex processes. Not only did the lessons learned from accidents remain reactive and limited to technical and procedural aspects, but more importantly, the effectiveness of the Rex processes did not seem to be questioned. Given these findings, the ACIO EDIA sites seemed to have developed effective tools for correction at the first (organizational single loop learning) level (behaviour and procedures) but had failed to develop a reflective approach questioning the effectiveness of their Rex processes.

The principles we have stressed in this second part specifically enable us to reveal the weaknesses of Rex processes of the ACIO and EDIA sites resulting in (among other things) organizational single-loop learning. Integrating the three categories of weak signals which we have identified in each of the first three principles of the Delft model - risk identification and building of accident scenarios, implementation of safety barriers and of the resources – to ensure their better functioning, would encourage the sites to adjust the tools and practices of their Rex, as well as the frameworks of their communication schemes (from closed to open). These revisions would help and encourage the passage from organizational single-loop learning to double loop learning.

6.3.2.1.4 Formalize learning

To be effective, organizational learning should result in a significant change at operational and organization level. To ensure that this is a lasting change, organizational learning must be organized.

The work of Koornneef (2000) provides an interesting perspective here, in that it describes the functions necessary for the organization of learning. The main contribution is certainly that of the Learning Agency. This needs to be made explicit (the function needs to be allocated explicitly to appropriate employees), in order to play the essential role of coordination and analysis of the safety data in support of the decision-makers. Explicit designation of such an agency would allow both sites to solve, at least in part, the organizational fragmentation blocking current learning, and would represent a practical and lasting measure for sharing lessons (see section 2.3.2.2.2).

6.3.2.2. Contribution of a sociological approach: the limits of the Delft Model and the relevance of weak signals as an object to observe

This last section aims at summarizing the contributions of Delft model but also its limits. The Delft model helps to formalize the structure, functions and resources needed to put a learning organization in place, based on notification and treatment of operational surprises.

This model gives a part of the answer to the issue of weak signals. Although it provides a structure to detect them (principle of risk identification), and a learning system to take them into account, we may observe some limits. In fact, the results derived from our case studies show that an organization should be basically well organized to put this model in place. More precisely, we demonstrated that both of our cases (EDIA and ACIO) were fragmented organizations, which not only generated but also maintained the formation of weak signals. We showed that a fragmented organization has difficulties to learn from complex or unknown data (because they are discarded by the current tools of data processing) and, hence it has problems in becoming fully a learning organization. This result is consistent with proposition 3.

The reader may be frustrated in the sense that we have not clearly answered the question as to what are weak signals. We believe that weak signals are not a specific type of signal, which could provide an answer to the questions asked in section 3.1.1. They are any type of information which is difficult to detect and treat, in a specific organizational context. Weak signals are not an issue that can described in positive terms; they are or become weak because of how they are treated. Their study reveals the organizational dynamics, and more specifically the factors that contribute to make these signals weak. In that perspective, the issue of weak signals, and particularly this PhD, is a contribution to an understanding of complex organizations which have to face complex information. If we admit that the structure of an organization, generating, as it does, fragmentation of work coordination, communication and learning, is a relevant blocker that impedes the recognition and treatment of weak signals, we may conclude that, even with the application of a "well-structured" model, an organization cannot learn from all of its operational surprises. The model may describe an ideal functional state, but reality never matches it.

To finish, we believe that a sociological approach, as set out in this thesis, has provided a substantial –but limited- contribution. On the one hand, it has enabled us to question and define weak signals and keep our distance from the existing, common definitions which could have led us into an intellectual trap; namely that weak signals are substantial accident warnings that may prevent a given accident. On the other hand, we showed that the application of a model is necessary but not sufficient. The diagnosis of an organization, implying the study of an existing learning system (Rex process) and normal functioning provide some interesting clues to understand why and how an organization weakens signals and maintains their weakness through its process of information processing.

In summary, the results proposed in the previous sections refer to three levels of the organization: the identification of three categories of weak signals, the fragmentation of safety management and information filtering process, and finally organizational fragmentation - as roots of the persistent weakness of signals. We have then formulated recommendations aimed at resolving them, which we have focused on one part of the organization as example, though we believe that the general approach described can be applied all across the companies concerned.

Part 6.4 of this chapter presents the contributions and limitations of action-research.

6.4 The requirements of action-research

Action-research was considered the most relevant and potentially fruitful approach to deal with weak signals because it allowed us to make a bridge between diagnoses based on sociological case studies, and the operational implementation of recommendations.

However, once the decision has been made to deploy it in an organization, many pitfalls may arise to weaken this project: academic constraints - combining academic research and operational results - and personal constraints.

6.4.1 Action-research constraints

6.4.1.1 Academic requirements

The first constraint was the time allocated to conduct this research. In four years, my objective was to carry out this project and to achieve four stages: literature review, case studies on the two sites, analysis and formalization of data and, finally, feedback sessions.

This action research required a double competence (see Methodology chapter). The first was a descriptive step that led to the gathering of the necessary data to conduct situational diagnoses in the field in both companies. To do so, I carried out case studies using a qualitative approach (interviews, observations, literature review) keeping in mind the following question: what are the strengths and weaknesses of the learning systems at the ACIO and EDIA sites?

These data required articulation of two sets of knowledge: organizational sociology and management/engineering science concepts such as organizational learning in the domain of safety. The second step was prescriptive. To analyze and transform the results found and propose to the ACIO and EDIA sites ways of improving their systems of learning. For this I dealt with applied models providing a method to solve the problems identified. The models proposed by Koornneef & Hale appeared relevant in that they combined implementation of organizational learning with pursuing a goal of improving safety management (see second part of this chapter).

Finally, I conducted my research in the Safety Science Group (Delft University of Technology) in the Netherlands, which required supervision in English – the common language of student and supervisors. However, all the field work in the two French company sites and the seminars set up by FonCSI took place in French. The use of both languages, but also the requirement imposed by the Delft University of translation of the thesis from French to English, represented an additional difficulty shared by my supervisors for whom French is not their native tongue, but a third language.

This thesis was a double learning for me: to mobilize knowledge and competence in the management (and engineering) sciences, with all that implies in theoretical rigor, both methodological and practical, and to integrate it with my sociological background, and to complete an ambitious research project within two complex technical activities (steel making and oil refining) with strong engineering cultures. This required me to question my own knowledge and learning processes.

6.4.1.2 Personal involvement

In order to carry out the case studies and visit the sites on a daily basis for periods during a year and a half, I moved close to the ACIO and EDIA sites. Beyond the practical aspect, living in this region of France was a way to reduce the gap that can otherwise be an obstacle between my status as “foreign” researcher and the people working on the site who mainly come from the region. My status as outsider was repeatedly recalled through innocent questions such as what was my hometown and the place where I was living. I tried as far as possible to be accepted, by learning the local language and the local culture, and by sharing the genuine interest of operators and managers for their work and company, and making connections (sometimes friendships) with people on the sites.

This involvement is not without danger of introducing biases and assumptions. Therefore I made sure not be too caught up in the organization, tried to avoid too intimate "professional" relationships and to keep a distance from the values or standards (the culture) which pervaded the two companies. Being inside and winning confidence, but also maintaining an “outsider” position to capitalize on the role of researcher (I was considered as a student or a trainee) was necessary to access and appraise data as independently as possible. Thus, I always had to try to find a compromise between the two positions, even though it seemed that perfect balance is not possible in practice. It is a constant and conscious search for the best position. In the field, through my daily social exchanges, I was always listening, talking and sharing, but avoiding introducing my own judgments. This researcher identity – not insider and not outsider - is only tenable for a limited time. Therefore the case studies had to be completed in that time, to put an end to that endless search for the perfect posture and to the fantasy of being able to observe and capture the full reality of the field.

6.4.2 Achieving action-research, a trifle?

6.4.2.1 Action-research limitations

The conditions for carrying out this action research depended on the involvement of the sites in my research and access to their data. As such, the conditions created by the EDIA and ACIO sites were quite different (see section 3.2.2.1) but both allowed me to collect the data necessary to conduct this research and develop sociological diagnoses.

After the "research" part of the work, I tried to conduct the "action" part of my thesis which included, in theory, one or more feedback sessions, making and discussing recommendations and monitoring/supporting their implementation (or not) on the sites. It is clear that, in practice, I have not been able to achieve all of these steps. Two reasons can be invoked. First, because of the economic crisis that hit industry in October 2008, the ACIO site did not consider that setting up feedback sessions within my time constraints was a priority. Then, for personal reasons, work on my thesis had to stop for nine months, from October 2008 to April 2009, just after an initial feedback to EDIA, which prevented any opportunity for further feedback of results during this period. This left time after resumption of work only for the feedback to EDIA headquarters set up in July 2009.

Finally, supporting and monitoring the sites in the implementation of recommendations was not achieved for two reasons. First, due to the delays and stoppages in the work my data were only partially treated by July 2009, so I could not propose the recommendations presented in section 2 of this chapter during the second feedback with EDIA headquarters. Also the research team thought it preferable, at this second EDIA feedback, to present first the results and, according to reactions, to propose or not further recommendations. Despite the receptivity of the participants, there was not sufficient enthusiasm for further research or direct implementation of the results and recommendations. Hence the 'action' part of the action-research was not established, either on the ACIO or the EDIA sites.

However a more generic attempt was made to capture the lessons from this research in a "self-evaluation guideline" for use by companies to assess the capability of their safety management systems to detect and respond to weak signals. This is described in the next section.

6.4.2.2 Self-evaluation guide of Rex processes taking account of weak signals

This final chapter summarizes the comparison of the results derived from the two case studies, as well as some recommendations. I realize that these recommendations focus on specific levels of the two company's systems and it remains difficult to solve, through a limited research project, the deep problems of an organization. This action-research did, however, also include the writing of a practical guide (appendix 15). This document was required by FonCSI, the financier of this thesis. They asked me to provide a method of questioning Rex practices and, more particularly, the integration of weak signals in them.

The development of this guide was a challenge, first of all because FonCSI required a short, operational and usable guide. This work was challenging since it required me to make a series of questions designed to assess the effectiveness of this aspect of safety management, based on the Delft model. In addition I included the issue of weak signals (Sheets 3, 4 and 5, appendix 15). These questions were designed to encourage the sites applying the guide to assess their sensitivity to, and consideration/treatment of weak signals in safety management. The elaboration of the guide was the opportunity to transform results into operational recommendations, but it was no easy task, certainly one that most researchers would find easy to get involved in, since it requires translating the results of an academic study (even though an applied one) into results which are intelligible and operational for practical managers and engineers.

This guide is not summarizing this research. As we mentioned above, it was required by FonCSI as output, but it does not reflect the whole work done during these last five years. It is more an experimental tool (in that it has never been applied) and it should be reviewed and validated to become, according to the FonCSI's requirement, an operational tool. It is also based on a method, itself based on research and academic concepts which requires some explanation or clarification. The theoretical understanding of the context in which this guide has been developed determines the quality of results. We believe that the use of this guide by industrial sites must be supervised, so that it is not used as yet another tool for data collection but considered as a real opportunity for analysis and processing of the weak signals of accident.

6.4.2.3 A project to be carried on?

Can we conclude that this action-research has been completed? Can we even say it is an action-research? Given the topics developed in the Methodology chapter, action includes feedback of results and implementation of recommendations, essential steps of action-research because they allow the transmission, exchange and operationalization of the results of research within a project of mutual learning. However, we showed that all these steps have only been partially implemented. Two answers can be provided to these questions.

First, action-research is not only defined by the action aspect but also by the effects of the presence of the researcher in the field. I have included in section 5.5 an analysis of the results of my presence as a way to reveal some issues relating to the research object. The limits of the effect of my involvement in the analysis of accident 1 confirmed the limitations of the Rex process and of the underlying information processing, limited to known data, which had already been experienced, but also showed my powerlessness or lack of legitimacy (the status of a young researcher) in the face of the (experienced managers of) two sites when trying to make an impact on issues as deeply rooted as those found.

The incompleteness of this action-research reveals that the feasibility of this approach depends on the economic context of the companies in which the researcher is involved, but also on their involvement or commitment to change through such action-research. It was interesting to observe the effects of my presence and actions on the sites and to use these as one means to evaluate the maturity of the sites to undertake a reflexive learning process to improve their safety management (see part 4.5). Finally, action Research enables us to assess the limits of sociology when it aims to creating a dynamic of learning within an industrial site. The bridge between researchers and industry is still difficult to cross, and I hope that this thesis will contribute to a productive discussion on this topic.

7. Conclusion

We have addressed in this thesis the issue of weak signals in terms of the sociology of organizations and found the following results.

1. First conclusion.

First of all, through the conduct of two case studies, we identified three categories of weak signals:

- -Technological weak signals defined as latent, repetitive technical failures and for which the methods of detection, analysis and correction seem inadequate to solve the problem identified,
- -Weak signals related to the coordination of work, especially in relation to maintenance contracting, that result in the construction of informal practices which compensate for the incompleteness or inappropriateness of a rule or procedure but which are not perceived as threats to safety,
- -Weak signals relating to the underestimation of risk which are rooted in shortcomings in proactive and reactive risk analysis that underestimate the actual and potential risks related to the equipment or use of it.

We showed through the analysis of four accidents and incidents that these signals were not seen as clear threats to safety, and were therefore discarded from the Rex process. They were revealed to be relevant information when the link between these signals and the accident sequence was restored through event analysis. We concluded that it was difficult to notice these weak signals because of their qualitative, fragmented and complex characteristics (see first hypothesis, section 1.4). In order to be identified and taken into account, weak signals require a process of sense-making before the event by actors of a group of actors in a position to take action or to transmit them to actors or group of actors with that authority or power.

2. Second conclusion.

We hypothesized that organizational factors prevented the two sites making sense of weak signals. We set out to identify the factors that prevented actors in the organization from making sense of these signals. Initially, the persistent weakness of signals is the result of fragmentation within or between three activities of safety management:

- -Technology management, or more precisely the tools and methods of analysis of repetitive anomalies,
- -Safety management and especially the interfaces between sub-contractors and ACIO and EDIA operators,
- -Completion of proactive and reactive risk analyses.

These activities were shown to be compartmentalized and independently managed, from data collection to processing, and we noted a lack of interconnection between these three activities of safety management.

Then, within each of these three activities, we observed a process of information filtering which tended to distinguish between two types of data. On the one hand, we identified known or simple data, that is to say, data for which the detection and analysis tools and organizational mechanisms for managing and monitoring were predefined. These data get a simplified treatment, that is to say that the analysis and actions put in place to remedy the problems identified tend to be limited to the immediate technical and/or procedural aspects, with only marginal treatment of the organizational factor. On the other hand, more complex, unexpected data or weak signals, unlike the former, cannot enter, or are discarded from the information management system, because they do not fit within the classifications or predefined treatment categories. The fragmentation of safety management and the process of filtering information have been defined as two factors blocking the taking into account and treatment of the three categories of weak signals.

In a third step, we wanted to show that these two factors blocking the detection and treatment of weak signals were, in turn, rooted in the organizational structure. Organizational fragmentation was shown to result in a distinction or desynchronization between the staff and line (operational) organization of work, particularly in relation to maintenance. Where the resources made available to operators to perform their work (procedures, competence, information, technical and/or organizational barriers) are incomplete or inadequate, this encourages them to violate or bypass the rules and create informal practices that suit the pressures of work and the constraints of business. These practices, which may threaten safety, nevertheless keep the system functioning and may in some circumstances be tolerated and normalized by management. The centralization and complexity of prescribed rules, leading to necessary adjustments, were shown to be a fertile seedbed for these informal practices, and to be implicated in the persistent weakness of the signals related to coordination and underestimation of risk. This conclusion confirms the second hypothesis announced in introduction of this PhD research.

3. Third conclusion.

As a consequence of all this, and it responds to our third hypothesis, the ACIO and EDIA sites do not derive the organizational double-loop lessons from the three categories of weak signals, though these would offer the opportunity to identify and treat organizational dysfunctions on safety, that is to say, failures of safety management and those inherent to the organizational structure and its learning (Rex) system.

4. Fourth conclusion.

In an operational perspective, we also intended to propose recommendations designed to assist the sites to identify and treat the weak signals of accidents, and use these as real levers of risk prevention. Building on the model of the Delft method (Hale and Guldenmund, 2004), we first demonstrated the need to make sense of weak signals. This approach calls for opening up the categories of detection and data transmission, to open the organization to observe unexpected and unplanned for data (or surprises) which can transmit information anticipating threatening phenomena, namely accidents. Also, the linking of these data - weak signals - with other known data seems necessary, and should be developed while pursuing a clear objective: the prevention of accidents. The Delft model suggests the explicit identification of accident scenarios which allows the modelling of accident sequences that can potentially occur on a site, the barriers to their occurrence and the resourcing of the functioning of those barriers. Based on these scenarios, we proposed that the way forward is to define the three categories of weak signals as indicators of accident deviation derived from operational activities, and also to identify the barriers and safety measures to capture and respond to these early signals of accident.

We showed that the three categories of weak signals pointed to the inadequacy or incompleteness of three barriers (in the accidents studied) that should ensure equipment and staff safety - technical barriers (e.g. equipment lock-out), organizational barriers (work permits) and risk analysis developed in upstream operations - and the incompleteness of the resources provided for the functioning of these barriers - training and knowledge about risks of equipment (e.g. the steam line), the clarity and applicability of the rules and procedures and communications about them (e.g. the coordination meeting) leading to violations and conflicts over the commitment to safety above other company or personal objectives and the availability of human resources (e.g. supervision).

Based on this assessment of the safety management of the EDIA and ACIO sites, through the prism of the Delft model, we have suggested that the sites should revise their proactive risk analyses, incorporating lessons learned from accidents and the three categories of weak signals that we have identified (which can occur in many accident sequences). On the other hand, it is important to provide better availability of staff during the works, so that any anomaly or unexpected situation can be managed and coordinated locally (as opposed to over-centralization and complexity of administrative procedures). Improving these organizational arrangements would cut down the bypassing of the prescribed rule in some cases where these are inappropriate to the context of maintenance operations. This would respond to the weakness of signals related to the coordination of work and the underestimation of risk.

Paying attention to these weak signals would encourage learning. If they were to become better integrated at every level of safety management, i.e. risk identification, construction of accident scenarios, the definition of barriers and resources for ensuring the continued functioning of those barriers, they would be a lever to achieve the passage from organizational single-loop to double-loop learning, that is to say, from a learning based mainly on action limited to technical and procedural dimensions, to a learning based on the revision and readjustment of tools and resources defined as central characteristics of safety management. Organizational double-loop learning contributes to maintaining control adapted to the changes inherent to the activity of the site but also coming from the environment.

These propositions confirm our fourth hypothesis. In fact, we assumed that the Delft model could partially respond to the issue of weak signals. The model was applied to a specific part of the system and raised specific issues, which enables us to address a limited view of the Delft model. We believe that a model, in itself, is a limited response to a complex and broad issue such as the treatment of weak signals of accidents. As we proposed in this thesis, such a model may be enriched by other approaches, more defined by their descriptive and inductive characteristics. By conducting a sociological diagnosis in two industrial sites, we showed to what extent weak signals were not a specific object of study in the companies. They revealed organizational factors - coordination, communication and learning fragmentations- that block the treatment of signals and make them weak and the limits of a prescriptive model.

Finally, I wish to make two remarks. I applied an action-research methodology in such a way as to combine the sociology of organizations with the operational management of safety, which has determined the nature and content of the results obtained and described in this thesis. I do not exclude, in fact quite the contrary, the existence of other relevant and efficient methods for processing weak signals. The thesis is a project of limited duration that does not explore all possibly relevant theoretical fields and actions. The issue of weak signal definitely needs a cross-disciplinary study – encompassing management sciences, psychology, and sociology - and operational methods in order to tackle it in all its complexity.

The results of the thesis are not exhaustive since we studied a limited number of cases and since our observations focus on a few specific activities of the two sites. Nevertheless, this work has managed to clarify the concept of weak signals and identify common features between the EDIA and ACIO sites. Can these conclusions be transferable to other sites? Can the organizational factors identified as the root of the persistence of weak signals here, be observed in other high risk organizations? If this happens, the perspectives of research on the identification and treatment of weak signals of accidents are encouraging.

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Appendices

APPENDIX 1: Interviews guide, accident analyses

1. Accident circumstances
- What kind of work was being conducted when the accident happened?
- Who was present? Are there any witnesses?

2. Information reporting
- Who detected the information? Who transmitted the information?
- What message was transmitted?
- Through what kind of communication channel was the information transmitted: oral, written, electronically?
- Was it a formal (tool, procedure) or informal communication channel?
- Were any actions immediately put in place?

3. Information treatment

    -Accident severity

- Does the site use a severity scale to rate an accident? Which one?
- Who is in charge of rating an accident?
- Who is in charge of validating this rate?

    -Scoring and event analysis

- Who is filling in the event report?
- Who is analyzing it? On what method is this analysis based? How are the causes of the accident defined?

    -Treatment and severity

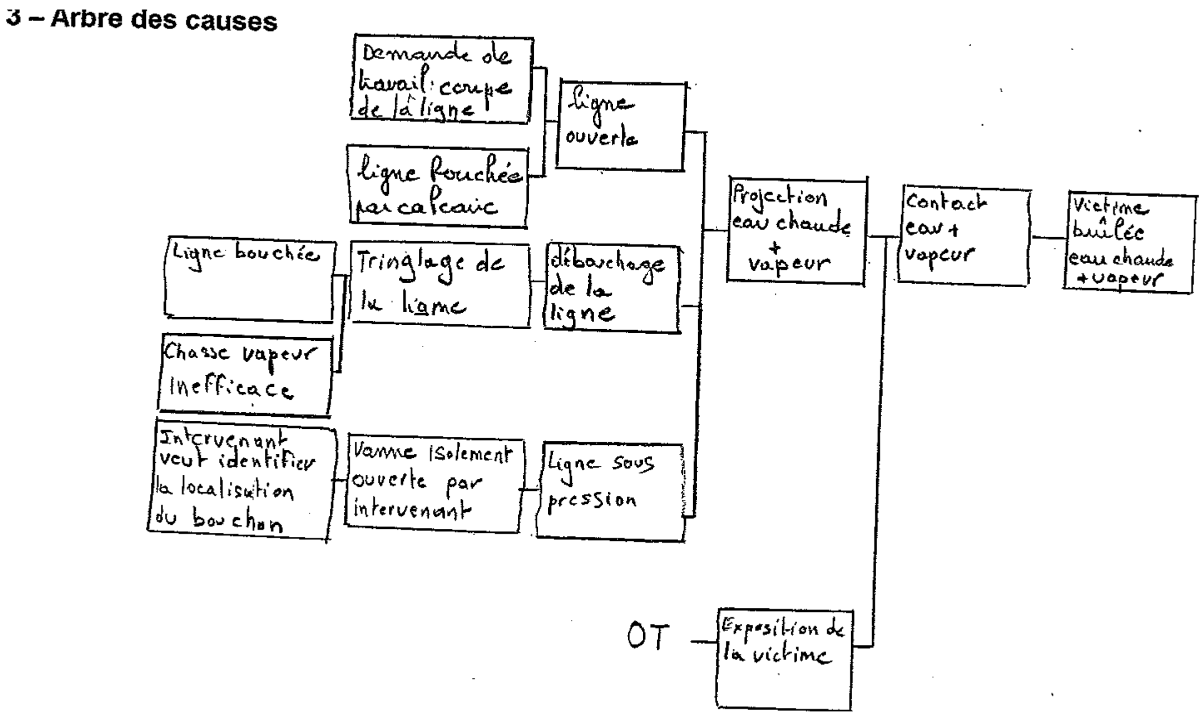
- Does the site apply a specific procedure to treat severe accidents (severity A).

    -Treatment and Rex

- Who is transmitting the information to the Rex Team?
- On what criteria is an event selected as a « Rex event »?
- How does the Rex team treat the event? Are any lessons drawn from the accident?
- Does the Rex team share the lessons with the other sites?

4. Lessons learnt
- What lessons have you learnt? What actions did you implement?
- Do you plan to assess the relevance and efficiency of actions?

APPENDIX 2: Accident fault tree analysis, EDIA



The picture is of bad quality but I wanted to keep it as it was designed and produced to show documents that the EDIA site produced.

APPENDIX 3: Accident Rex form, EDIA

BRULURE D'UN INTERVENANT PAR PROJECTION DE VAPEUR ET DE CONDENSATS	BURN OF A WORKER BY PROJEC-TION OF STEAM AND CONDENSATES
1. <u>RESUME DES FAITS</u> Un intervenant d'une société extérieure a été brûlé aux 1er et 2ème degrés par de la vapeur et des condensats alors qu'il tentait de déboucher une ligne de vapeur qu'il venait de découper puis de remettre en pression par ouverture d'une vanne d'isolement. Dans le cadre d'une campagne de débouchage de lignes vapeur, une ligne vapeur a été coupée par un intervenant d'une société extérieure après avoir été préalablement mise à disposition par l'exploitant. Constatant la présence d'un dépôt obstruant la ligne au droit de la coupe, l'intervenant a alors tenté de déboucher la ligne par tringlage. N'arrivant pas à éliminer complètement le dépôt, l'intervenant a pris la décision d'ouvrir la vanne d'isolement de la tuyauterie puis a frappé la tuyauterie. Sous l'action de la pression de vapeur, la ligne s'est débouchée brusquement et l'intervenant a alors reçu une projection de vapeur et de condensats lui occasionnant des brûlures au 1er et au 2ème degré au ventre et aux cuisses. **2. <u>CAUSES</u>** Les causes immédiates et fondamentales suivantes ont été identifiées lors de l'enquête : - Non respect de l'autorisation de travail : l'intervenant a entrepris une opération de débouchage non prévue dans l'autorisation de travail, - Non respect des procédures : l'intervenant a manoeuvré une vanne d'isolement utilisé par l'exploitant pour la mise à disposition. **3. <u>ACTIONS DE PROGRES</u>** 1- Rappeler au personnel des entreprises extérieures les règles de respect des autorisations de travail 2- Rappeler au personnel des entreprises extérieures la règle de non manœuvre du matériel d'exploitation.	**1. <u>SUMMARY</u>** A worker of an outside company was burned at the 1st and 2nd degree by a projection of steam and condensates while he was trying to unplug the steam line he had just cut then put back in pressure by opening a valve of isolation. During a campaign of cleaning steam lines, a steam piping was cut by a worker of an outside company after having been put out of operation by the refinery staff. Noticing the presence of a deposit inside the line in the right section of the cut, the worker then tried to unplug the line using a piece of iron wire. Not succeeding to eliminate the entire deposit, the worker took the decision to open the isolation valve of the line and then struck the piping. Under the effect of the steam pressure, the line suddenly unblocked and the worker then received a projection of steam and condensates causing him 1st and 2nd degree burns on his stomach and on the thighs. **2. <u>CAUSES</u>** The following immediate and root causes were identified during the analysis: - Non compliance with the work permit: the worker decided to try to unplug the line which was not planed in the work permit, - Non compliance with the operation procedures: the worker has moved a valve of isolation used by the refinery staff to hand-over the steam line. **3. <u>ACTIONS OF PROGRESS</u>** 1- Remind to the staff of outside companies the rules for work permit 2- Remind to the staff of outside companies the rules of non moving operation equipments (valves by eg).

APPENDIX 4: Workforce audit, EDIA

Service PRÉVENTION

[redacted]

AUDIT de CONFORMITÉ des CHANTIERS

N° 04842

Heure : ________ Auditeur : ________ Service : ________

Entreprise Extérieure 1 : ________ Nbre d'intervenants : ________ N°du bon de Validation : ________

Entreprise Extérieure 2 : ________ Donneur d'ordre : ________

	PERSONNEL EE		PERSONNEL RF		OBSERVATIONS
	Conforme	Non conforme	Conforme	Non conforme	
TRAVAIL Le BV est signé et le travail effectué correspond bien à celui notifié. Les contrôles d'atmosphère ou condamnations sont écrits et réalisés.					
EPI Les équipements de protection individuels de base sont portés, les bras et les jambes sont couverts.					
PROTECTIONS SPÉCIFIQUES Les équipements de protection spécifiques mentionnés sur le BV sont portés par les intervenants.					
MOYENS UTILISÉS Les outils et moyens mis en œuvre sur le chantier sont tous stipulés sur le BV. Les engins ont été contrôlés par le PCI.					
MESURES PRÉVENTIVES Toutes les mesures préventives mentionnées sur le BV sont respectées.					
PROPRETÉ La zone de travail est propre, les outils rangés, les déchets correctement conditionnés et stockés. Les équipements de sécurité sont libres d'accès.					
INTERDITS Les interdits relevant du règlement général sont respectés.					

CHALLENGE SÉCURITÉ : ________ **POINTS**

Exemplaire ENTREPRISE : ROSE
Exemplaire SERVICE SÉCURITÉ : JAUNE
ARCHIVE : BLANC

APPENDIX 5: Severity scale applied to workforce audits, EDIA

ANALYSE du NIVEAU de GRAVITE

Protections individuelles

Niveau	*Anomalie*
1	Casque
1	Gants
1	lunettes , écran facial , lunettes étanches
1	Chaussures ou bottes adaptées
1	Bras et jambes couverts
1	Masque à poussiéres
2	3 anomalies en même temps.

Protections spécifiques

Niveau	*Anomalie*
2	Harnais , ligne de vie
2	Tenue de sablage
2	Tenue travaux HP ou THP
2	Tenue protection chimique
2	Masque de fuite , détecteur H2S
2	Détecteur O2
2	Explosimétre individuel
2	Gilet de sauvetage
2	Masque FPP3

Protections collectives

Niveau	*Anomalie*
2	Balise d'explosivité
2	Etayage des travaux de fouille
2	Balisage tir radio
1	Balisage travaux avec projection
1	Balisage travaux de levage
1	Balisage travaux de fouille
2	Bache pare étincelles

Documents associés

Niveau	*Anomalie*
2	Bon d'explosivité
2	AT/BV non conforme au travail ou non signé
2	Permis de fouille
2	Bon ou n° de consignation
2	Permis CACES ou autorisation de conduite
2	Habilitation electrique
2	Annexe 2 (arrêté du 4-09-1967)
1	Fiche de soudage
1	Fiche prévention d'abord

Comportements & Interdits

Niveau	Anomalie
2	Tabac , Alcool
2	Téléphones portables
1	Stationnement , Circulation
1	Franchissement de barrières
2	Franchissement de barrière GPL
2	Utilisation d'échafaudages non réceptionné
2	Modification d'échafaudage
2	Plaque de répartitions pour grues de levage

Procédures & Mode opératoire

Niveau	Anomalie
2	Travaux dans les capacité
2	Plan de platinage
2	Plan de levage
2	Procédure de retrait amiante
2	Procédure de tir radio
2	Utilisation réseau incendie
1	Utilisation réseau air service

APPENDIX 6: Scheduled General Inspections, EDIA

Révision : 03
Date : 23/05/2006

ANNEXE 1

GUIDE POUR LA REALISATION
DES INSPECTIONS GENERALES PLANIFIEES

CONDITIONS DES LIEUX DE TRAVAIL

PLANCHERS (aires de déplacement)

a. propres, en ordre et salubres
b. bon écoulement des eaux
c. pas de danger de glisser, de tomber
d. pas d'objets/de parties en saillie
e. ouvertures couvertes ou interdites

PLATE-FORMES ET ECHAFAUDAGES

a. plate-formes de travail : au moins 600 mm de largeur
b. plinthes de 100 mm sur tous côtés
c. garde-corps de 1 m avec sous -lisse
d. planchers adapté à l'usage
e. assises solides
f. pas d'accumulation d'outils ou de matériaux
g. pas de modification en cours d'usage

ISSUES DE SECOURS

a. suffisantes pour évacuation rapide
b. pas de verrouillage ni de fixation
c. trajets/issues clairement indiqués
d. issues bien éclairées
e. abords des issues dégagés
f. portes s'ouvrant sur l'extérieur et donnant sur une surface horizontale
g. au moins 650 mm de largeur

ROUTES

a. chaussée en bon état
b. signalisation standard

ALLEES

a. bonne signalisation
b. aucun obstacle à la circulation
c. largeur suffisante pour tous les mouvements normaux
d. au moins 65 cm de largeur

ESCALIERS

a. au moins 600 mm de largeur
b. marches uniformes en hauteur et en profondeur
c. pas de contre-marche si les marches ont moins de 225 mm de profondeur
d. marches des escaliers extérieurs en caillebotis
e. garde-corps sur les côtés ouverts
f. gabarit vertical d'au moins 2m10
g. aucun obstacle à la circulation
h. escalier en bon état

ECHELLES

a. barreaux exempts de graisse
b. une seule personne à la fois dans l'échelle
c. échelles bien fixée
d. échelles en mauvais état : étiquettes DANGER

PARKING ET CLOTURES

a. signalisation correcte des parkings
b. clôtures en bon état
c. pas d'objet le long des clôtures

Etat du document : Document validé

Révision Fichier : 06

BATIMENTS

VENTILATION

a. ouvertures disposées
b. entrée continue d'air extérieur
c. gaines d'air étanches

ECLAIRAGES

a. éclairage suffisant des zones de travail et de déplacement pendant les périodes d'occupation
b. appareils d'éclairage propres
c. éclairages de secours sur tous les parcours d'évacuation non éclairés normalement

BRUIT AMBIANT

a. protection des travailleurs en cas de niveau de bruit trop élevé

ERGONOMIE

a. installations permettant des postures normales assises ou debout
b. commandes permettant l'utilisation avec les vêtements et l'équipement normalement portés
c. limite de poids ou de taille des objets soulevés/transportés à bras

MATERIAUX

STOCKAGES

a. corridors/parcours d'accès libres
b. empilages stables sans risque de glissement ou d'écroulement
c. zone de stockage propre et libre de matériaux ou objets étrangers
d. limites de charges sur étagères affichées et respectées

MANUTENTION

a. conteneurs en bon état
b. palettes en bon état
c. chaînes, élingues et câbles adaptés aux charges et en bon état
d. bon rangement du matériel de levage

PRODUITS CHIMIQUES

a. fûts en acier ou autre matériau adéquat
b. réservoirs munis d'évents ou de soupapes de sûreté
c. réservoirs mis à la terre
d. cuvette de rétention
e. produits absorbants à proximité
f. bon supportage des réservoirs/fûts
g. température contrôlée
h. récipients portatifs en bon état
i. prévention de la corrosion

GAZ COMPRIMES

a. bouteilles stockées debout et retenues pour ne pas tomber
b. bouteilles groupées par contenu et marquées clairement
c. capuchon en place serré à la main
d. stockage éloigné des sources de chaleur, des escaliers et trajets d'évacuation

ELIMINATION DES ORDURES

a. conteneurs en nombre suffisants
b. conteneurs distincts pour les produits inflammables
c. absorbants pour produits chimiques à portée de la main dans la zone travail

ETIQUETAGE DES MATERIAUX

a. étiquettes standard apposées sur tous les contenants de substances dangereuses en cours de stockage et d'utilisation
b. étiquettes standard sur les véhicules transportant des matières dangereuses
c. étiquettes bien en vue et lisibles

DISPOSITIFS DE SECOURS

EXTINCTEURS

a. à portée de l'utilisateur
b. en cours de validité

COUVERTURES DE SECURITE

a. équipement adéquat et bien situé
b. équipement protégé

DISPOSITIFS DE MISE EN GARDE

a. alarmes en état (incendie, H2S,...)
b. alarmes de surpression
c. alarmes de surchauffe
d. mise en garde pour les voies de chemin de fer

DOUCHES ET LAVE-OEIL

a. facile d'accès dans les endroits où on utilise des produits agressifs
b. alimentation en eau pour au moins 15 minutes et à bonne température

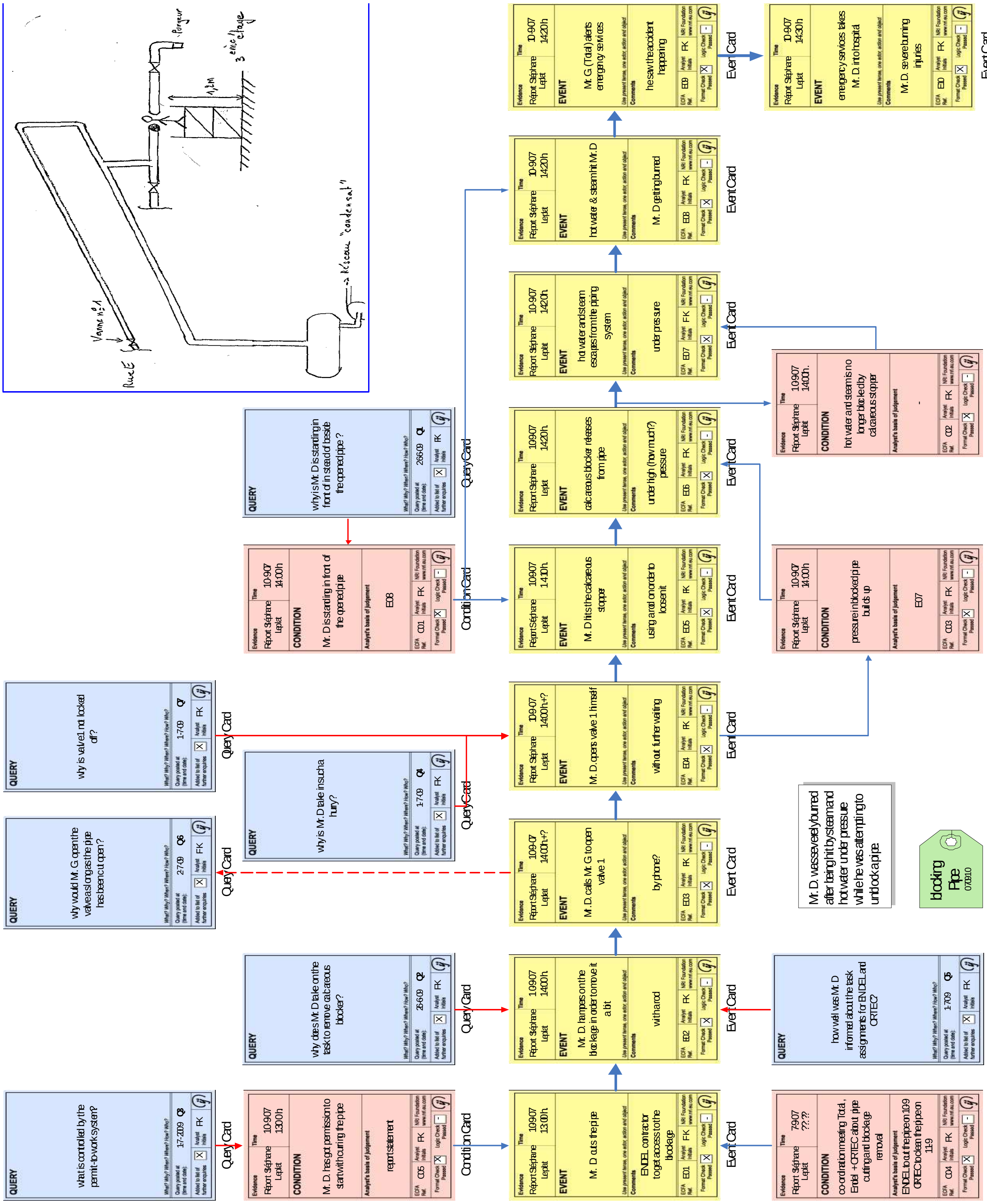
APPENDIX 7: Quality audit form, EDIA

Anomalie(s) constatée(s)	RISQUE A = majeur B = sérieux C = mineur	Action préconisée	Responsable	Délai
Date, Nom, et Visa du Responsable de la tournée :				

Destinataires : - **Chef du secteur concerné**
- **Responsables d'actions**
- **DQ/QA** (Archivage : 3 ans)

Référence : IMTRF001 Rév. 04 du 06/01/2006 P. 2/2
Etat du document : Document validé Révision fichier : 06

APPENDIX 8: ECFA+ method applied to EDIA accident



APPENDIX 9: Steel making process, ACIO

La Cokerie : le minerai de fer (matière première de l'acier) est reçu par bateaux sous forme de grains (minerais fins). Il faut agglomérer ces minerais pour former de plus gris morceaux. Cette opération est réalisée par cuisson sur la chaîne d'agglomération. Le charbon est cuit dans les batteries de four de la cokerie pour former le coke. Cette opération produit des gaz qui vont être traités au sein de l'unité « traitement du gaz ». Un dégoudronneur permet ainsi d'extraire le goudron contenu dans le gaz de cokerie. Ce gaz traité est acheminé vers deux gazomètres et permet d'alimenter d'autres installations de l'usine.

Les Hauts-Fourneaux : Les minerais agglomérés, le coke et les minerais crus sont ensuite chargés dans le haut-fourneau (le site est doté de deux hauts-fourneaux) et cuits à 1400 degrés. La combustion du coke permet d'extraire le fer des oxydes de fer et de le porter à la température de la fusion (quelle °C ?). De la fonte liquide coule à la base du haut-fourneau.

Aciérie : la fonte est transportée à l'aciérie dans des wagons spéciaux appelés poches tonneaux protégés par des briques réfractaires. L'excès de carbone contenu dans la fonte est éliminé dans un convertisseur à l'oxygène. L'acier sauvage est alors traité dans une station d'affinage pour régler précisément sa composition chimique finale définie en fonction de la demande du client. L'acier en fusion est coulé en continu dans un moule sans fond de la machine de coulée continue. En traversant ce moule, il commence à se solidifier au contact des parois refroidies à l'eau. Le métal moulé descend, guidé par un jeu de rouleaux et continue à se refroidir. A la sortie, le ruban de métal d'épaisseur de 250 mm est entièrement solidifié. Il est coupé en brames aux longueurs voulues.

Train continu à chaud : les brames arrivent au TCC. Elles sont réchauffées dans un four pour rendre le métal plus malléable, puis amincies en passant entre les cylindres de 12 cages successives du laminoir (bandes fonctionnant à une vitesse de 4km/heure environ) Elles produisent des bandes de tôles de quelques millimètres d'épaisseur. Elles enroulées en bobines. Des opérateurs en salle d'opération contrôlent le procédé de laminage. Une caméra filme le passage des bandes pour détecter des anomalies de qualité.

Energie : Le département Energie a pour fonction de distribuer sur l'usine toutes les énergies nécessaires au fonctionnement des installations : électricité, gaz et eau. Il existe deux types de gaz : le gaz industriel (air comprimé, azote et oxygène) et les gaz sidérurgiques (gaz d'aciérie, de cokerie et des Hauts Fourneaux) fabriqués par l'activité du site. La distribution de l'énergie est assurée par le dispatching. Le département Energie joue un rôle central dans la gestion des accidents majeurs. Lorsqu'un accident survient, et que ses conséquences réelles ou potentielles pourraient être aggravées (sur le site ou en dehors), le département opérationnel dans lequel l'incident s'est produit, le département Energie et les pompiers ont la charge de déclencher un POI (Plan d'Opération Interne : gestion d'un accident majeur au sein du site). Si l'accident a un impact qui dépasse les limites du site, le PPI (Plan Particulier d'Intervention) est déclenché et pris en charge par la préfecture.

Laminage à froid, site de Spiker[53] : Les bobines sortant de l'usine ACIO sont acheminées vers trois sites de laminage à froid. Spiker est spécialisé dans le relaminage à froid, le décapé, la tôle mince, la tôle galvanisée à chaud et le packaging.

Toute usine confondue, les bobines servent à 51,5% au revêtu (dont 76,7% destinés à l'automobile), 15,8% à l'emballage, 11,5% à la tôle mince nue (dont 43,6% pour l'automobile), 10,9% pour le décapé et 10,3% pour le coil noir.

[53] Spyker is not part of ACIO case study.

APPENDIX 10: Works meeting report, accident 1, ACIO

ARRET BRIQUETAGE AB5048

COMPTE RENDU DE LA COORDINATION DU 01/08/08

Concernant le Plan de Prévention N°43961 établi le 17/07/2008

Coordinateurs :

Tableau de bord

SECURITE	***Remarques ponctuelles :*** Compte-rendu des audits de la veille **CTA : quasi accident : déplacement du CTA par le bull, en présence du personnel de la SNEF sur le chantier (préventif fins de course)** **TRAVAUX DANS CR AVEC TEMPÉRATURE ÉLEVÉE : 56°C** **Travaux 59 m : conditions de travail difficiles, dû au refoulement du CR4**

DELAI	- **Chemin critique : RAS** 152 – Nettoyage banquettes & fosse non faite MULTISERV Le début des essais est, **à ce jour**, reporté au 04/08/08 10H30 au lieu de 08:00. La fin des essais reste fixé au 05/08/08 04:00 . Les retards sur le briquetage, dû aux conditions de travail (température), n'ont pour l'instant pas d'incidence sur la durée de l'arrêt ; **reste 1h00 de marge !!!**

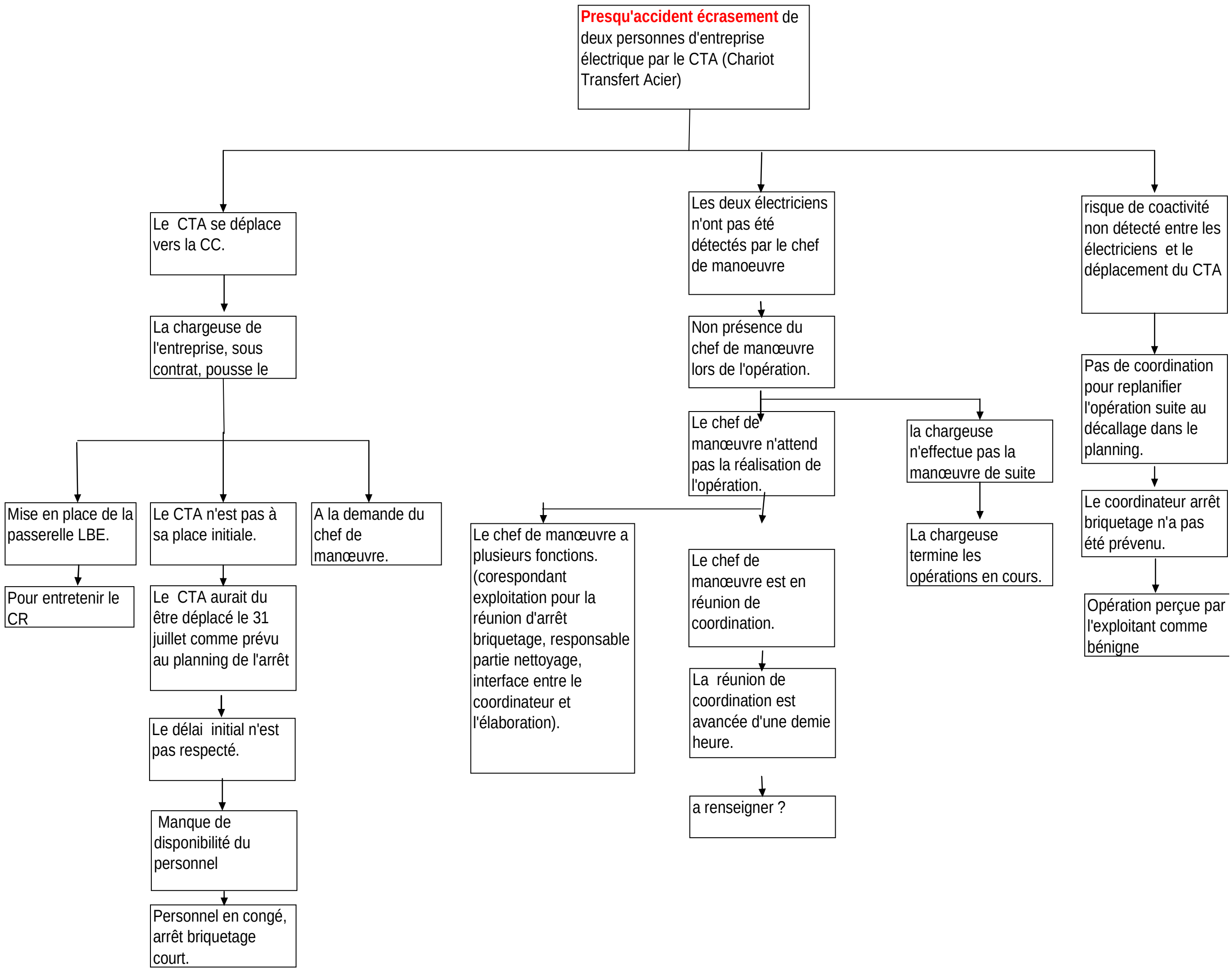
ORGANISATION	

Modifications décidées

Activités	Mesures
3001	CPH: NETTOYAGE TIRANTS & CPH le 01/08/08 21:00-02/08/08 05:00 ONET
3002	NETT CONDUITE HORIZONTALE DEFLECTEUR le 02/08/08 05:00-13 :00 ONET
46	BRIQUETAGE 1 & opérations liées prolongé jusqu'au 02/08/08 21:00 gleser
265	PASS.T.POCHES : PREVENTIF MECANIQUE prolongé jusqu' au 02/08/08 13:00 SDMI
1005	ANALYSE GAZ : MODIF RAIL DE GUIDAGE ASSECHEUR A GAZ reporté au 02/08/08 06:00-12 :00 SNEF
1036	R.G.A: RESSUAGE CLOCHE HAUTE reporté au 02/08/08 08:00-12 :00 COFICE
242	MAQ . PREVENTIF MECANIQUE avancé au 01/08/08 13:00 SDMI

AKKA Page 1 sur 2 01/08/2008

APPENDIX 11: Fault tree analysis, accident 1, ACIO



Plan d'actions :

Actions préventives décidées :	**PILOTE**	**DELAI**	**CLOTURE**
1- Rappeler à l'ensemble des acteurs des arrêts, de signaler tout retard au coordinateur d'arrêt (règle de fonctionnement des PdP).	R.		
2- Redéfinir le rôle du chef de manœuvre pour les opérations de déplacement des chariots, avec une chargeuse, lors des arrêts (procédure à écrire).	P.		
3- Ajouter une consignation mécanique lors d'opération sur les voies (pince rail).	R.		
4- Rédéfinir le rôle de la vigi "pont" pour les opérations de maintenance en halle des poches.	R.		

APPENDIX 12: Rex notice, accident 2, ACIO

2005
Nr

Retour d'Expérience Sécurité

Nature :	☒ Incident ☐ Accident ☐ Accident mortel	Personnel :	☐ Arcelor ☐ Sous-traitant ☐ Autre	Date: 12/02/05	Heure : 22h

Établissement Arcelor:	Secteur :	Sous-secteur :	Pays :
Dunkerque	Plats Carbone	UO Centre-Europe	France
Secteur d'activité :			

Nom du Sous-traitant	Secteur d'activité :

Nature de l'accident	Mots Clés
Coup de feu	Coup de feu, explosion

Description :

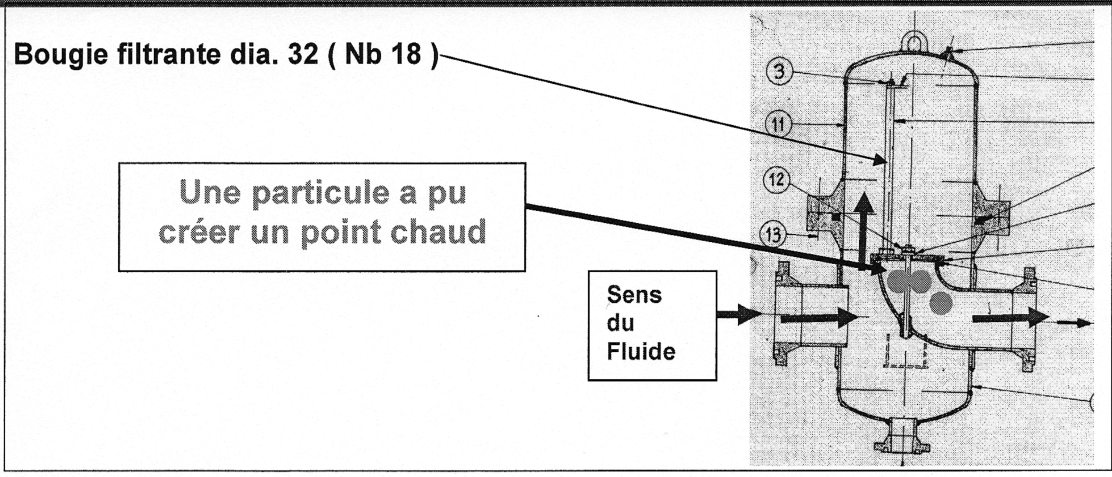
Le 12/02/2005 à 22h un coup de feu s'est produit sur la ligne N°1 oxygène du poste de détente alimentant les convertisseurs de l'Aciérie.
Le coup de feu s'est produit au niveau du filtre et a détruit environ trois mètres de collecteur en aval.

Les premières constatations :
Cette ligne avait subi un entretien programmé le 02/02/2005 par le remplacement de toutes les bougies filtrantes.
Cette installation était en réserve depuis ; pour des raisons d'exploitation cette ligne à été mise en service et c'est après 4 heures de fonctionnement normal que le coup de feu s'est produit.

A 22 heures, constat d'une chute de pression avec intervention immédiate de l'exploitant qui constate les dégâts et la fuite d'oxygène consécutive, ainsi que l'absence de flamme.
La conduite est alors isolée à l'aide d'une vanne manuelle.

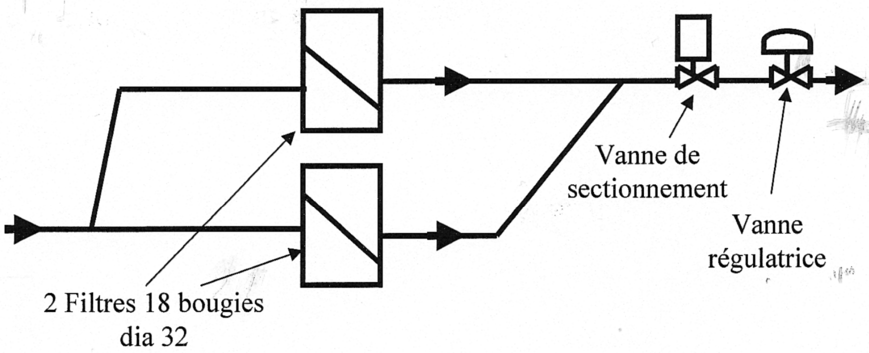
Actions engagées (entre autres) : voir schéma plus bas
L'enquête menée avec les spécialistes de l'Air Liquide sont les suivantes :

Le coup de feu a pris au niveau du filtre.
Hypothèse probable: coude attaqué par l'intérieur:
1 ou plusieurs bougies cassées créent un passage préférentiel entraînant une survitesse au niveau du coude ou de la tige.
Une particule a pu alors créer un point chaud et c'est la cause de l'explosion

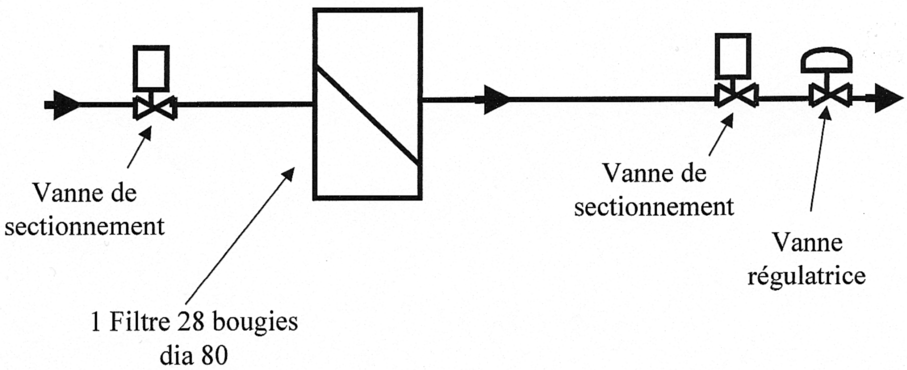


ACTION : On remplace les 18 bougies diamètre 32 par 28 bougies diamètre 80

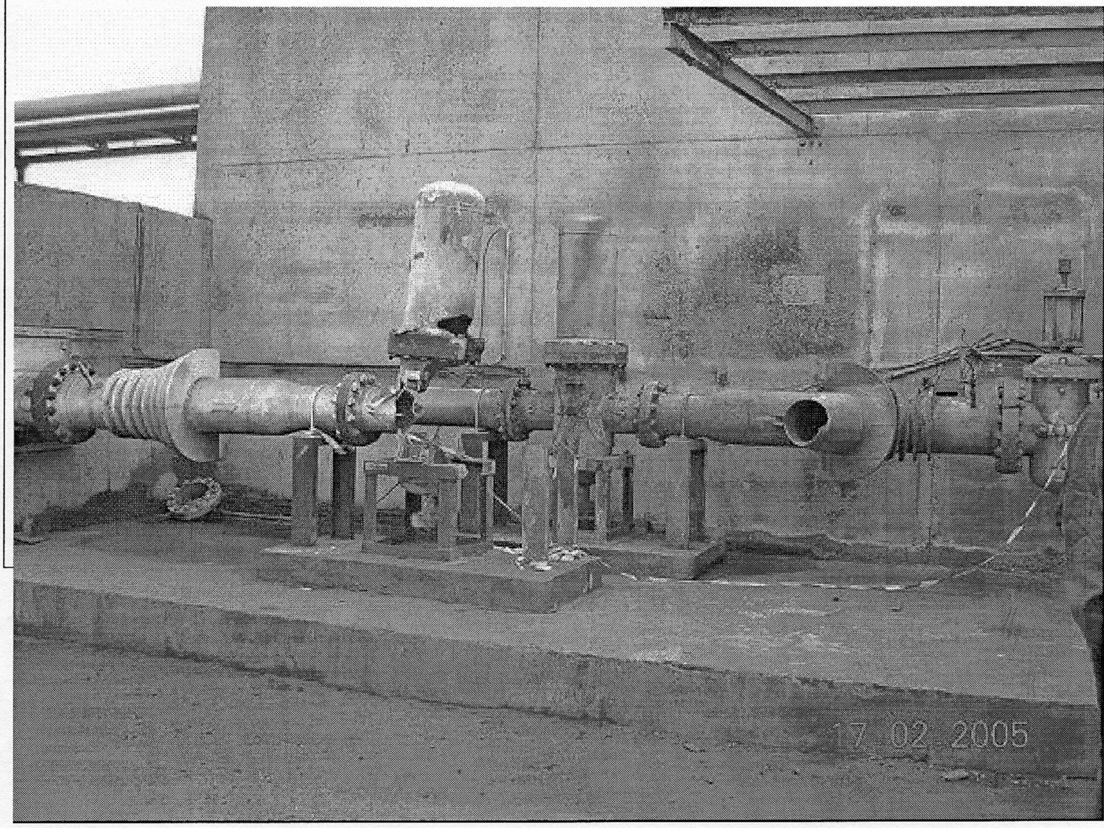
Ancienne configuration



Future configuration



Photos :



Personne de contact pour renseignements supplémentaires :

APPENDIX 13: Revised risk analysis, accident 3, ACIO

Installation : Aciérie / Désulfuration				Phase de fonctionnement : Normal					Date : 09/08/2004		
N°	Produit / Equipement	Situation de danger	Causes	Conséquence		G*	Barrières de sécurité		G	O	Améliorations
				Phénomène	Cible atteinte		Prévention	Protection			
1	Dépotage CaC2	Fuite	Rupture flexible Défaillance raccord Erreur humaine : mauvais positionnement organe (vanne), non-respect du mode opératoire	Auto-inflammation suite formation acétylène avec humidité de l'air	1 personne en permanence (conduites gaz à 20 m)	3	Changement flexibles tous les ans Maintenance préventive Mode opératoire dépotage **sous N2**– formation (PDP)	~~Dépotage à l'air avec contrôle Humidité –~~ Asservissement arrêt dépotage si seuil dépassé **C2H2** Intervention secours Commande à distance pour arrêt ~~air comprimé~~ **N2**	3	3 3 3	
2		Fuite + présence d'eau	Idem 1 + présence eau dans local : vent, pluie rentre par les rails	Inflammation instantanée du CaC2	1 personne en permanence (conduites gaz à 20 m)	3	Changement flexible tous les ans Maintenance préventive Mode opératoire dépotage **sous N2** – formation (PDP) + Local protégé en partie pour dépotage	~~Dépotage à l'air avec contrôle Humidité –~~ Asservissement arrêt dépotage si seuil dépassé **C2H2** Intervention secours Commande à distance pour arrêt ~~air comprimé~~ N2	3	2 3 3	
3	Stockage CaC2	Entrée humidité dans silo	Perte surpression ~~air~~	Auto-inflammation suite formation acétylène avec humidité de l'air Eclatement	Installation	3	Surveillance pression ~~air~~ **N2** avec report d'alarme en salle de contrôle Conception-inspection **Surveillance O^2 en continue du ciel silo. Surveillance C2H2 en**	Détection acétylène dans le silo est asservie inertage ~~azote~~ **Argon** Event de surpression **ou membrane anti-déflagrante**	3	2	

APPENDIX 14: Coordination meeting procedure, ACIO

Dunkerque, le

Objet : Modification Plan de Prévention

Plan de Prévention n°

Monsieur,

A la suite de la réunion de coordination en date du ________________ , il a été convenu, compte tenu des données nouvelles concernant les travaux en cause, de modifier partiellement le plan de prévention cité en référence.

Nous vous prions de bien vouloir trouver-ci-joint ces modifications (pages modifiées : n° ____________________

____

____

Elles sont d'application immédiate, vous voudrez bien les intégrer dans l'exemplaire du plan de prévention qui vous a été remis.

Elles annulent et remplacent les pages antérieures de même numéro.

Comme les textes vous en font obligation, vous voudrez bien informer le personnel intervenant sous votre autorité du nouveau contenu du plan de prévention, et vous assurer du respect de ses dispositions.

Veuillez agréer, Monsieur, nos salutations distinguées.

Le représentant de l'Entreprise Utilisatrice :

APPENDIX 15: Self assessment guide

Foreword

The development of this guide is based on two case studies, and has never been tested on site. Users should therefore take into account the limits of the guide and its possible incompleteness.

Context

This guide is based on thesis work included in the research program "Socio-cultural factors of a successful Rex process" launched by the FonCSI in November 2005. It follows the recommendations that were made in the thesis.

In this thesis, two case studies were conducted: one on a steel plant at ACIO and a second one on an EDIA refinery. The results showed that, despite the establishment of a system to prevent accidents, both sites were faced with difficulty in identifying and processing weak signals as precursors of an accident.

This guide aims to support industrial organisations managing high risk activities in taking into account operationally and effectively the weak signals of potential accidents.

The guide consists of three parts:

1. Definition of and issues related to weak signals
2. Question sheets
3. Blocking factors of three categories of weak signals.

The responses of the site to these will enable it to assess whether its safety management system can identify and deal effectively with the weak signals of potential accidents.

Part I. Definition of and issues related to weak signals

The importance expected of weak signals is that they are indicative of a potential accident. Management of risks by taking into account weak signals is important for two reasons:

-To encourage operators, managers, directors and Safety and Environment managers to focus their attention and vigilance on early signs of the loss of control of risk

-To promote the ability to recognize patterns and causes of these signals in order to better anticipate the risk of accidents.

The more organizations are trained to observe these signals, the more they will be able to implement an effective method of treatment of weak signals.

How do weak signals develop?

Weak signals are pieces of information or messages whose strength is low or has been weakened so that it is not interpreted as a threat to safety. The strength of these signals remains low because filters (see Figure 1) prevent such information from being taken into account by the systems of safety information. They remain latent information within the organization. The latter makes sense of this information mostly only when an accident has occurred, because the relationship between these signals and the accident is revealed only during the analysis of the event.

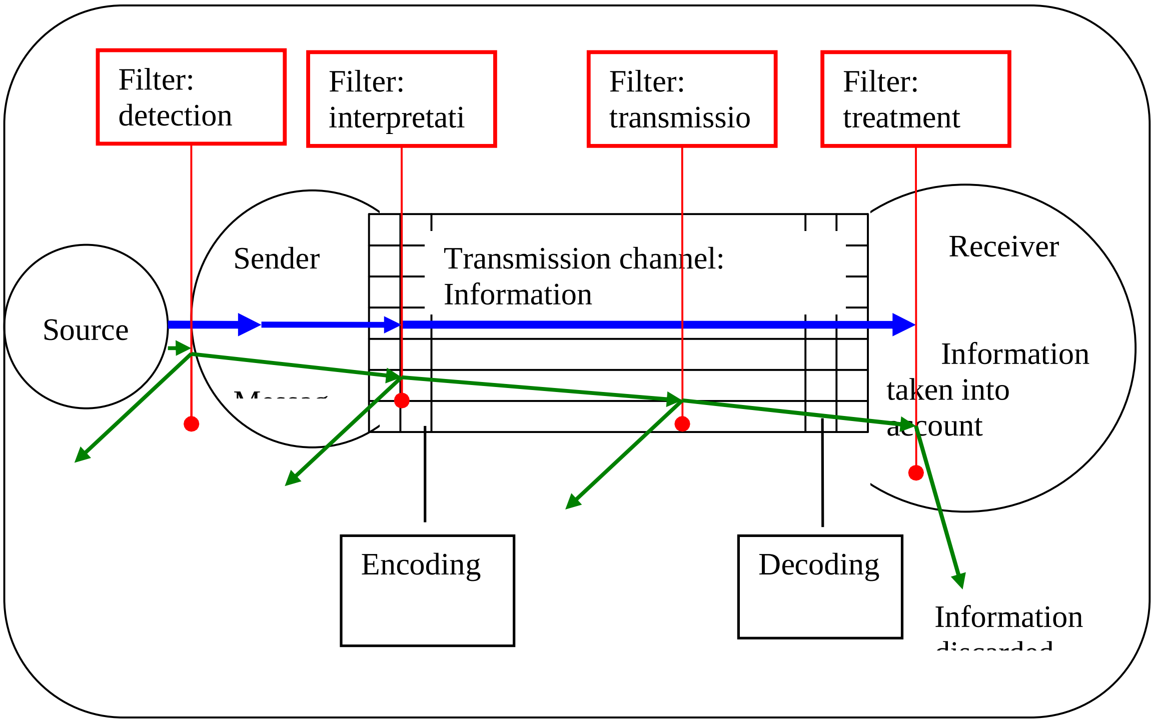


Figure 1: Filters in the communication chain

Green arrows: discarded information

Blue arrows: information taken into account (including weak signals treated)

The filters are of three kinds: they are to be found in information system tools, individual or collective knowledge and expertise, or organizational arrangements.

1. Detection step includes:

   -The use of tools (e.g. audits of behavior)

   -The mobilization of knowledge and experience of 'detectors'

-A device to detect "surprises" or unexpected data (e.g. a learning agency or group of people dedicated to this task).

2. The interpretation step includes:

-The tools that define the nature and severity of data (e.g. in a computerized management tool for anomalies)

-The expertise mobilized by individuals or groups of individuals in a meeting to process anomalies (e.g. trade-offs made to determine the severity of an event),

-Methods to interpret surprise data (in the learning agency or group of experts).

3. The transmission step consists of:

-The transmission channels used to route data to relevant audiences (e.g. a computerized management tool for anomalies)

-The process of individual or collective decision to mobilize a communication channel and the most appropriate recipient(s) to treat the data collected,

-Exploring new formal but also informal communication channels.

4. The treatment includes:

-The tools to address the problems encountered,

-The expertise to identify appropriate preventive or corrective actions to solve the problems identified,

-Innovative methods of analysis and treatment to take into account the "surprises" detected (within working groups and interdepartmental forums, training, etc.).

5. Learning involves:

-Changes to remove the causes and influencing factors,

-The ability of the site to identify some of these devices (tools, expertise, organizational arrangements) as factors blocking the processing of weak signal treatment,

-The ability to question and modify the presence or working of these filters.

These filters can play two roles:

-Amplify, and therefore take into account a data set fitting the framework of the predefined tools. These filters do not usually leave room for the observation of surprises,

-Discard other data that do not fit predefined categories in the tools defined above.

Which signals it will be which are or become weak depends to a certain extent on the tools used by the site to detect anomalies and emerging risks. The strength of these tools can be their weakness in that the more they amplify one sort of information or signal, the more they may hide or discard information that does not fit those categories, i.e. new or unexpected information.

Why do signals remain weak?

The literature and case studies we conducted show that organizations managing a risky business should establish a risk control model based on the notions represented in the model in figure 2. This shows the principles of risk management. At the heart of the company activity (operating, maintenance and engineering of the refinery, for example), safety barriers are put in place upstream of the central event (the “Undesirable event" in Figure 2) to block or divert the accident sequence, and barriers are placed downstream of the central event to reduce the severity of the consequences of the event. Technical (physical) barriers are generally well defined; their operation and failure, which must be detected and monitored (technical or procedural defects), are also generally well identified, recognized and taken into account. Behavioral barriers or behavior necessary for physical barriers to operate effectively are often less well identified and mapped. The resources to establish and keep the barriers functioning well are indicated by the vertical lines from the processes of design engineering, maintenance and operations. Models explicitly specifying all of these features can be used to locate where signals for monitoring effective functioning of the system can be located or found.

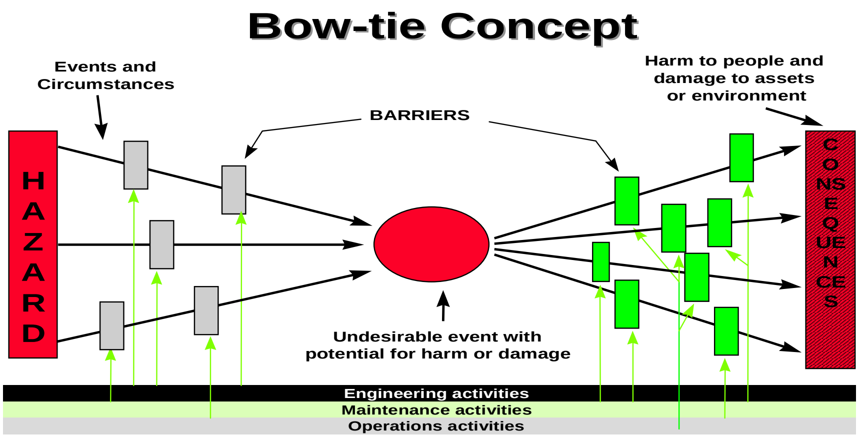


Figure 2: Bowtie, representation of risk management

If data relevant to the functioning of these barriers or resources, which also emerge from the site activity, remain poorly identified and therefore not integrated in the accident sequence (scenario) management they will be and stay weak. Two reasons lie behind this finding. First, where the poorly known data are signals of organizational dysfunction (an aspect little taken into account in safety management), these data would be excluded (see figure 1) because their nature and configurations do not fall within the categories used for analysis (or the encoding process).

Secondly, these data are often complex, ambiguous, and require an analytical approach based on a comprehensive and integrated method, which enables us to make sense of these data. However, our case studies have shown that both sites were characterized by fragmentation, not integration of safety management:

Fragmentation of safety management was visible as independent treatment of:

-Anomalies

-Critical events

-Major injuries

A failure in the allocation of resources to address the problems identified

-A surfeit of unrelated tools (for detecting anomalies, for example),

-Compartmentalization of departments in charge of data management (maintenance manages technical anomalies, safety service behavioral anomalies and major accident service the hazard studies).

Against this background which is defined by fragmentation of safety management and an organizational mechanism for filtering information, we showed that the two cases studied were characterized by a relative lack of a comprehensive and integrated approach to manage risk. These defects led to both:

-Difficulty to recognize, integrate and process weak signals as precursors of accidents,

-Learning limited to procedural and technical corrections (single loop learning).

In addition to the methods already identified, to detect and correct the range of deviations, it is necessary that sites develop methods to detect and correct organizational weak signals of loss of control of risk. We define and give specific examples later.

Part II. Question sheets

Objective

The purpose of this guide is to assist sites in setting up a method for identifying the type of information we have called "weak signals" upstream of the accident.

This guide consists of five sheets that form the framework for the questions. They require to be completed in total.

SHEET 1: RISK ANALYSIS

1. Has the site identified all the risks inherent to its activity?
    a. Major accidents
    b. Accidents/incidents within the bounds of the site
    c. Occupational accidents
2. If some risks have not been identified:
    a. For what reasons ?
    b. What does the site plan to do to identify these risks proactively?
3. For each category of risk, did the site build credible accident scenarios?
    a. Are these scenarios built in terms of accident sequences (following the bowtie model or an equivalent)?
    b. Using what databases were they built (Rex database for example)?
    c. Do they cover all three categories of risk (see question 1)
4. For each scenario, did the site put safety barriers in place to block or divert the accident scenario?
    a. Are the specific safety barriers suitable to prevent the specified risks?
    b. Are these barriers put in place upstream of the central event (see bowtie figure 2)?
    c. Are they also put in place downstream of the central event in order to reduce the consequences of the central event?

SHEET 2: IDENTIFY RESOURCES FOR RISK CONTROL

5[54]. For each of the scenarios, have the **resources** been systematically put in place to guarantee the good functioning of the barriers? Do they cover?

a. Analyzing the risk that the barrier are designed to prevent?

b. Defining the best combination of barriers and the functioning they require?

c. Putting these barriers in place and monitoring their efficiency?

d. Improving, if necessary, their efficiency?

6. For each technical barrier, does the site ensure the following steps?

a. Design, purchase, and putting the safety barriers in place

b. Their functioning and use

c. Their maintenance and improvement

7. For each human barrier, does the site ensure the following steps?

a. Defining or putting adequate procedures in place for the use of equipment or a technical barrier

b. Selection and training of operators and other staff so that they are competent to control risks by their behavior

c. Ensure sufficient number of people allocated for safety tasks

d. Ensure efficient communication and coordination between people responsible for safety tasks that require coordination

e. Ensure that safety is a first priority over all other objectives, and that safety tasks are carried out and equipment used

[54] Questions 5, 6 and 7 assess the development of resources and organizational arrangements to prevent or block the accident scenarios previously identified. These resources and devices must be defined and must be monitored.

SHEET 3: IDENTIFYING THE WEAK SIGNALS OF ACCIDENTS

8. For each scenario, did the site identify signals within the defined accident scenarios which are currently weak e.g. less known risks, signals of organizational failures in resource allocation, repetitive patterns, etc. that may emerge from the operational activity? Are the following indicators at least followed-up:

- a. Technical weak signals:
  - i. Repetition of technical anomalies on the same or different equipment
  - ii. Persistence of specific technical anomalies despite maintenance works carried out
  - iii. Analysis of causes of this repetition
- b. Weak signals relating to coordination of contracting work:
  - i. Possession of, and compliance with work permits are systematically checked
  - ii. Suitability of the work permit for the work to be conducted is analyzed (is work permit complete, adapted to the context of works?)
  - iii. Work permit delivery is systematically checked
  - iv. Distribution of tasks is clearly defined (with company staff and between contractors)
  - v. Works are supervised by a works coordinator and a preventionist
  - vi. Critical practices[55], where modifications of practices may occur are monitored and detected through formal means (audits) or informal ones
  - vii. These practices or failures in coordination are assessed, analyzed and treated together with the people involved
  - viii. The task allocation in operational work, which may be a source of these practices can be questioned, revised and modified in order to prevent the persistence of these kinds of practices.
  - ix. Pressures (time, budget) may be a source of these practices
- c. Weak signals concerning underestimation of risk
  - i. Risks relating to all hazards are revised without any accident occurred, especially those where maximum credible accidents are assessed as low in consequences or probability
  - ii. Operator and managers' knowledge and risk perception are always assessed and revised thanks to trainings, safety meeting, information and field practice

9. Tools, collective and individual expertise, and organizational plans are put in place. to:

- a. Detect indicators of weak signals (see question 8 a, b and c)
- b. Transmit these signals through formal and informal channels
- c. Treat, i.e. put preventive and corrective actions in place in order to solve the problems identified.
- d. Draw out effective and lasting lessons on the basis of trating weak signals

[55] Manipulation of valves by contractors (non authorized) for example

SHEET 4: TREATMENT OF WEAK SIGNALS RELATING TO ACCIDENTS

10. Has the site identified organizational factors which may block the treatment of weak signals?

a. Did the site define the **filters** (relating to tools, expertise, organizational factors) which may block the treatment of weak signals in the Rex process?

b. Did the site identify the reasons why these filters are present despite their intrinsic limitations (see part 3)?

c. Has the site linked the presence of these filters with the persistence of weak signals?

11. Has the site a group of "experts" to analyze the reasons why weak signals are persistently not detected and treated?

a. Who is this group of experts composed of? Is it managed by the safety service?

b. Does this team have access to all data (technical anomalies, behavior, quality, Rex database, hazard studies)?

c. Are they trained particularly to detect surprises and to take them into account in the Rex process?

d. Do they use a method which enables them to analyze data in terms of accident scenarios?

11. Does the working of this group generate an efficient treatment of weak signals?

a. Do the actions put in place have sufficient effect on the organizational causes of weak signals (see question 8)?

b. Are actions followed-up by this group of experts ?

SHEET 5: LEARNING

12. Did the site put an evaluation of their safety management methods in place?

a. Does the group of experts evaluate regularly the relevance of the tools used to process accident and incidents, including weak signals (single loop learning)

b. Does the group of experts evaluate the learning method itself (double loop learning)

Part III. Blockers of weak signals

A. Technical weak signals

Technical weak signals in our study were repetitive signals which, despite being detected and even attempts to correct them, persist. Only the event analysis after an accident reveals the role of this technical anomaly in the accident sequence. These are weak because, until the accident, this information is not perceived as a significant threat to safety

> **Example 1**. After an initial fire on the oxygen hose at the filter, two operators operate the isolation valve against the rules and, despite the risks of this intervention (for operators, installation and environment), they succeed in stopping the leakage of oxygen and prevent a new outbreak of fire.

Lessons: Despite several maintenance operations on the cartridges on the oxygen line filter before the accident (interventions recorded in the management of technical deficiencies in the department concerned), the event analysis showed a lack of robustness and calibration of the filter cartridges. The defects have persisted, and were not seen as a sign of deterioration that could lead to a technical incident.

B. Weak signals « coordination»

This second category refers to the bypassing of the formal rule, felt to be necessary in situations of the complex interface between operators, contractors and outsourcers. Sometimes kept hidden and sometimes visible and tolerated by management, these informal practices are developed to keep the organization running, and gradually become normalized.

> **Example 2**. Following detection of limescale in steam pipes, two operations were planned on a specific line: a cutting operation by subcontractor 1, and a cleaning operation by contractor 2. After cutting the line, the operator of company 1 decided to clean the line. Without waiting for the company project coordinator, the contractor 1 put the line back in service in order to observe the passage of steam (despite the fact that subcontractors are not allowed to manipulate process valves). The blockage in line suddenly came free and the operator standing in front of the cut line, was hurt by steam and received second degree burns.

Lessons: Event analysis revealed that some experienced subcontractors were permitted to manipulate some process valves, a practice apparently tolerated by the management of the production units. These practices seem to have become habitual and not been identified as sources of risk anymore.

C. Weak signals « underestimation of risk »

This category refers to:

-Proactive risk analysis, that is to say in defining safety measures to be included in the design or installation of equipment, as well as safety measures that must be followed to use this equipment,

-Reactive risk analysis, that is to say made after an event (Rex) devoted to revising and modifying safety measures put in place.

These were, in our case studies limited, in most cases, to technical and procedural dimensions. They found it difficult to question the human and organizational factors of risks to be considered and controlled, and the effectiveness of the method of risk analysis itself, as set up by the site.

Curriculum Vitae

Eve Guillaume was born in Montmorency, France, on October 28, 1980. From 1995, she attended secondary school at Notre Dame de Bury in Margency, where she graduated in 1998.

In October 1998, she started her studies at the Department of Sociology, University of Saint-Denis. Then, she pursued her studies at the Department of Sociology, La Sorbonne, Paris, where she got her Research Masters degree in September 2003. She got a Professional Master degree applied to sociology of organizations from University of Dauphine, Paris, in November 2004.

From December 2004 to April 2005, she worked as a consultant in SNCF (French railways company).

In November 2005, Eve Guillaume started her PhD research at the Faculty of Technology, Policy and Management, Delft University of Technology, under the supervision of Prof. Dr. Andrew Hale, at the Safety Science Group. Her work as PhD results in the thesis “Identifying and responding to weak Signals to improve Learning from Experiences in High-Risk Industries”.

Summary

1. Context

This thesis forms part of an extended study funded by FonCSI (Fondation pour une Culture de Sécurité Industrielle) about learning systems of major hazard companies. All French industrial sites running a risky activity – e.g. petrochemicals, steel making plants – must put a Safety Management System in place, according to the Seveso II EC Directive[56]. Amongst other things, it requires implementing a Feedback of Experience process (Retour d'Expériences – Rex - in French). The objective of the Rex is to report and treat any critical events in order to prevent and avoid accident recurrences; it is composed of the following stages: detect, analyze, learn and share the lessons drawn from accident analyses.

Despite the use of Rex, many accidents still occur. Academics and industrials note that there are limitations to the Rex process (Gilbert & Bourdeaux 1999, Dien & Dechy 2007); it seems to be mainly reactive, and only to identify technical and procedural causes of accidents, which consequently limit the opportunities for learning – at the organizational level – for the sites. Researchers put the emphasis on means to promote and facilitate proactive safety management. Weak signals, defined as accident precursors, were perceived as a promising issue to meet such an objective. However, bodies of literature on weak signals (e.g. Caron-Fasan 2001, Brindejonc & Llory 2005 and Pariès & Bieder 2006) reveal the difficulty to recognize and treat them. They show that weak signals are fragmented and complex data which require a process of sense making to be carried out by the organization. We hypothesize that organizational factors block the treatment of these signals and maintain conditions in a favorable state, leaving these signals to persist in a weak state.

2. Objectives and methodology

The objective of this PhD research is to explore the research literature on Rex and weak signals, explore the theoretical underpinning and understand the functioning of Rex system and its strengths and weaknesses in practice. It aims at defining weak signals and identifying blocking factors in order to address theoretical and practical propositions to respond to this challenging issue. We conducted two in-depth case studies using the approach of action-research to provide a rich picture of how Rex in practice functions: the first in a petrochemical plant, EDIA, and the second in a steel plant, ACIO. We carried out a sociological diagnosis at both sites in order to

[56] The full name of the Seveso II transposition is the French decree May 10^{th}, 2000 "Arrêté du 10/05/2000 relatif à la prévention des accidents majeurs impliquant des substances ou des préparations dangereuses présentes dans certaines catégories d'installations classées pour la protection de l'environnement soumises à autorisation."

explore their maturity concerning weak signals management. From the cases we induce and hypothesize important filters and barriers to information transfer, comprehension and learning.

3. Results

Accident analyses and a study of normal functioning revealed that the EDIA and ACIO sites identified much data relating to safety, which were processed by the formal tools implemented and used on site, but discarded other data. We categorized the latter data in the following way:

-Latent and repetitive technical failures,

-Work coordination weaknesses

-Underestimation of risk.

We defined these data as **weak signals** because, with hindsight (during accident analysis), they revealed obvious and relevant information for prevention. Although identified as important data linked to the event, revealing organizational dysfunctions for safety, they were not perceived in advance as threats to safety and not included in the formal procedures of accident analysis. Neither site took the opportunity to learn from them; that is to say to deepen the analysis of the events (on the human and organizational dimensions) and to revise their own methods of investigation.

The case studies led us to identify the **roots of weak signals at two levels**.

- First level; safety management activities:

For each of the three categories of weak signals, a normal activity was defined as the mark or root of that specific category. Thus, the root of technical weak signals was found in the system of management of technical failures, the root of the “work coordination” weak signals in the relative inadequacy of the bureaucratic organization for the coordination of contractors’ work, and the root of the “risk perception” weak signals in limits to the proactive and reactive analyses of risks. Within each of these three activities, we observed a process of **information filtering** which tended to distinguish between two types of data. On the one hand, we identified known or simple data, that is to say, data for which the detection and analysis tools and organizational mechanisms for managing and monitoring were predefined. These data get a simplified treatment, that is to say that the analysis and actions put in place to remedy the problems identified tend to be limited to technical and/or procedural aspects, with only marginal treatment of the organizational factor. On the other hand, **more complex, unexpected data or weak signals**, unlike the former, cannot enter, or even are discarded from the information management system, because they do not fit within the classifications or predefined treatment categories.

The fragmentation of safety management and the process of filtering information were defined as two factors blocking the recognition and treatment of the three categories of weak signals.

-Second level: organizational structure

We showed that fragmentation and information filtering, blocking the detection and treatment of weak signals were, in turn, rooted in the **organizational structure**. Organizational fragmentation was shown to result in a distinction or de-synchronisation between the staff and line (operational) organization of work, particularly in relation to maintenance. Where the resources made available to operators to perform their work (procedures, competence, information, technical and/or organizational barriers) are incomplete or inadequate, this encourages them to violate or bypass the rules and create informal practices that suit the pressures of work and the constraints of business. These practices, which may threaten safety, nevertheless keep the system functioning and may, in some circumstances, be tolerated and normalized by management. The centralization and complexity of prescribed rules, leading to necessary adjustments, were shown to be a fertile seedbed for these informal practices, and to be implicated in the persistent weakness of the signals related to coordination and underestimation of risk.

By analyzing the Rex systems in this way, we rejected the theoretical formulation of weak signals as inherently weak and reformulated them as signals made or kept weak by the way they are handled by the learning systems of the company and their ability to detect, code, transmit and handle signals.

Finally, we addressed some recommendations. By comparing the EDIA and ACIO safety managements with the Delft model (Hale, 2003), we showed that both sites had gaps in operation of some specified principles of good practice. First of all, both sites did not manage to recognize and identify all the risks and to operationalize them in accident scenarios which could include the factors which potentially are weak signals. Then, there seems to be a weakness in the resources provided to ensure a continual assessment and reappraisal of the efficiency of the whole range of safety barriers necessary to maintain a good level of safety. Their safety management systems do not appear to be efficient in recognizing and treating such weak signals of accidents. Finally, both safety management systems proved to be not effective at organizational double-loop learning. The case studies showed that the EDIA and ACIO sites do not learn effectively from weak signals, because they still discard useful and important signals from their formal tools of accident analysis, whereas we believe that these signals have a huge potential for learning, for accident causes and for understanding and revision of the Rex process.

Samenvatting

1. Context

Dit proefschrift maakt onderdeel uit van een uitgebreide studie gefinancierd door FonCSI (Fondation pour une Culture de Sécurité Industrielle) naar de leersystemen van hoog-risico bedrijven. Alle Franse industriële sites waar risicovolle processen plaatsvinden – b.v. kerncentrales, petrochemische industrie, staalfabrieken – moeten krachtens de Seveso II EU Richtlijn[57] een VeiligheidsManagementSysteem (VMS) hebben. Naast andere zaken, vereist het de implementatie van een proces van leren van ervaringen (Retour d'Experiences – Rex – in het Frans). Het doel van de Rex is om kritische gebeurtenissen te rapporteren en te behandelen om herhaling van ongevallen te voorkomen; het bestaat uit de volgende fasen: detectie, analyse, leren, en delen van de uit ongevalanalyses geleerde lessen.

Ondanks het gebruik van Rex gebeuren er nog steeds veel ongelukken. Academici en industriëlen hebben vastgesteld dat er grenzen zijn aan het Rex proces (Gilbert & Bourdeaux 1999, Dien & Dechy 2007); het lijkt voornamelijk reactief en alleen technische en procedurele oorzaken van ongevallen te identificeren, wat daarom voor de sites de mogelijkheden beperkt om op organisatorisch niveau te leren. Onderzoekers leggen de nadruk op middelen om proactief veiligheidsmanagement te bevorderen en te vergemakkelijken. Zwakke signalen, gedefinieerd als ongevalsprecursors, werden als veelbelovend gezien om een dergelijke doelstelling te bereiken. Echter, uit de kernliteratuur over zwakke signalen (Caron-Fasan 2001, Brindejonc & Llory 2005 en Pariès & Biedermann 2006) blijkt de moeilijkheid om deze te herkennen en te behandelen. Aan de ene kant nemen we aan dat zwakke signalen gefragmenteerd zijn en complexe gegevens bevatten die een proces van duiding vereisen om de signalen zinvolle betekenis voor de organisatie te geven. Aan de andere kant postuleren wij de hypothese dat organisatorische factoren de behandeling van deze signalen blokkeren en de condities handhaven die gunstig zijn om deze signalen zwak te laten blijven.

[57] De volledige naam van de Seveso II transpositie is het Franse decreet van 10 mei 2000 “Arrêté du 10/05/00 relatif à la prévention des accidents majeurs impliquant des substances ou des préparations dangereuses présentes dans certaines catégories d'installations classées pour la protection de l'environnement soumises à autorisation.”

2. Doelstellingen en methodologie

Het doel van dit promotieonderzoek is om de onderzoeksliteratuur over Rex en zwakke signalen te verkennen, de theoretische onderbouwing te verkennen en de werking van Rex-systeem en de sterke en zwakke punten in de praktijk te begrijpen. Het is gericht op het definiëren van zwakke signalen en de blokkerende factoren te identificeren om theoretische en praktische voorstellen te ontwikkelen in antwoord op deze uitdagende kwestie. Wij hebben twee diepgaande casestudies uitgevoerd op basis van actieonderzoek om een rijk beeld verkrijgen van hoe Rex in de praktijk functioneert: de eerste in een petrochemische fabriek, EDIA, en de tweede in een staal-producerend hoogovenbedrijf, ACIO. Wij hebben een sociologische diagnose uitgevoerd op beide locaties om de volwassenheid met betrekking tot het managen van zwakke signalen te onderzoeken. Van de cases hebben we belangrijke filters en barrières inzake informatieoverdracht, begrip en leren afgeleid en geïnduceerd.

3. Resultaten

Ongevalsanalyses en een studie van het normale functioneren toonden aan dat de EDIA en ACIO sites veel gegevens met betrekking tot de veiligheid identificeren en verwerken met op de sites gebruikte formele instrumenten, maar andere data wegdoen. We hebben deze data als volgt gecategoriseerd:

-Latent en zich herhalende technische storingen,

-Gebrekkige werkcoördinatie, en

-Onderschatting van risico's.

We hebben deze data gedefinieerd als **zwakke signalen**, omdat zij, achteraf gezien tijdens analyse van ongevallen, voor de hand liggende en relevante informatie voor preventie onthulden. Hoewel geïdentificeerd als belangrijke data in verband met de gebeurtenis, en hierbij organisatorische disfunctioneren inzake veiligheid onthullen, werden ze niet van tevoren gezien als bedreigingen voor de veiligheid en niet opgenomen in de formele procedures voor ongevalsanalyse. Geen van beide sites maakte van de gelegenheid gebruik om hiervan te leren; dat wil zeggen om de analyse van de gebeurtenissen uit te diepen (t.a.v. menselijke en organisatorische dimensies) en om hun eigen onderzoekmethoden te herzien.

De case studies leidden ons naar de identificatie van de **wortels van zwakke signalen op twee niveaus**.

-Eerste niveau: veiligheidsmanagement activiteiten

Voor elk van de drie categorieën zwakke signalen was een normale activiteit gedefinieerd als het kenmerk of de wortel van die specifieke categorie. Zo werd de wortel van de technische zwakke signalen gevonden in het systeem voor het managen van technische storingen, ligt de wortel van zwakke signalen voor “werkcoördinatie” problemen in de relatieve ontoereikendheid van de bureaucratische organisatie betreffende de coördinatie van werkzaamheden door aannemers, en is de wortel van zwakke signalen voor “risico-onderschatting” in de beperkingen van proactieve en reactieve risicoanalyses. Binnen elk van deze drie activiteiten zagen we een proces van **informatiefiltering** met de neiging onderscheid te maken tussen twee soorten data. Aan de ene kant identificeren wij bekende of eenvoudige gegevens, dat wil zeggen de gegevens waarvoor de detectie- en analyse-instrumenten, evenals de organisatorische mechanismen voor monitoring en managen vooraf waren gedefinieerd. Deze gegevens krijgen een vereenvoudigde behandeling, dat wil zeggen dat de analyse van, en acties om de geconstateerde problemen te verhelpen de neiging hebben zich te beperken tot technische en/of procedurele aspecten, met slechts marginale behandeling van organisatorische factoren. Aan de andere kant, worden meer complexe, onverwachte gegevens of zwakke signalen, in tegenstelling tot de eerder genoemde, niet ingevoerd in, of verwijderd uit het informatiemanagementsysteem, omdat ze niet passen binnen de vooraf gedefinieerde classificaties of behandelingscategorieën. **De versnippering van veiligheidsmanagement en het proces van filtering van informatie zijn benoemd als twee factoren die het rekening houden met, en behandeling van de drie categorieën van zwakke signalen blokkeren.**

-Tweede niveau: organisatiestructuur

Wij lieten zien dat deze twee factoren die de opsporing en behandeling van zwakke signalen blokkeren, op hun beurt waren geworteld in de **organisatiestructuur**. Van organisatorische versnippering werd aangetoond dat dit leidt tot een onderscheid of de-synchronisatie tussen de staf- en de (operationele) lijnorganisatie van het werk, in het bijzonder in relatie tot onderhoud. Waar de middelen ter beschikking gesteld aan de operators om hun werk uit te voeren (procedures, bevoegdheden, informatie, technische en/of organisatorische barrières) onvolledig of onvoldoende zijn, moedigt dit hen aan de regels te schenden of te omzeilen en informele praktijken te ontwikkelen die passen bij de werkdruk en de beperkingen aan het werkproces. Deze praktijken, die de veiligheid kunnen bedreigen maar toch het systeem draaiende houden, worden, in sommige omstandigheden, getolereerd en genormaliseerd door het management. De centralisatie en de complexiteit van voorgeschreven regels, leidend tot noodzakelijke aanpassingen, bleken een vruchtbare voedingsbodem voor deze informele praktijken, en bleken betrokken te zijn in de aanhoudende zwakte van de signalen met betrekking tot de werkcoördinatie en de onderschatting van risico's.

Door op deze manier Rex-systemen te analyseren, hebben wij de theoretische formulering inzake zwakke signalen als zijnde inherent zwak verworpen en geherformuleerd als zijnde signalen die zwak zijn gemaakt of gehouden door de manier waarop ze worden behandeld in de leersystemen van de onderneming en hun vermogen om signalen te detecteren, te coderen, te verzenden en te verwerken.

Tot slot hebben wij gericht een aantal aanbevelingen gedaan. Door het veiligheidsmanagement van EDIA en ACIO te vergelijken met het Delftse model (Hale, 2003), toonden we aan dat beide sites leemten hadden in de werking van sommige gespecificeerde beginselen van goede praktijken. Allereerst zijn beide sites er niet in geslaagd om alle risico's en hun operationalisering in ongevalscenario's, die de factoren kunnen omvatten die potentieel zwakke signalen vormen, te herkennen en te identificeren. Tevens lijkt er een zwakte te bestaan in de middelen die beschikbaar zijn gesteld om te borgen dat continue evaluatie en herwaardering plaatsvinden van de efficiëntie van het gehele scala van veiligheidsbarrières die nodig zijn om een goed niveau van veiligheid te handhaven. Hun veiligheidsmanagementsystemen lijken niet efficiënt te zijn in het herkennen en behandelen van zulke zwakke signalen van dreigende ongevallen. Tot slot bleken beide veiligheidsmanagementsystemen niet effectief te zijn in organisatorisch dubbel-lus leren. De case studies toonden aan dat de EDIA en ACIO sites niet effectief leren van zwakke signalen, omdat zij nog steeds nuttige en belangrijke signalen verwijderen van de formele instrumenten van ongevalsanalyse, terwijl wij van mening zijn dat deze signalen een enorm potentieel hebben voor het leren inzake ongevalsoorzaken en voor het begrijpen en herzien van het Rex-proces.