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Accident investigation: From searching direct causes to finding in-depth causes – Problem of analysis or/and of analyst?

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ABSTRACT

Current operating feedback systems in industry show some limits since, in numerous industrial companies, the numbers of events do not decrease anymore and similar events seem to recur. Our assumption is that weaknesses come mainly from analysis methodology used. After a description of analysis methodology history, we focus on interest of applying an organisational analysis of events, familiar to scholars but not yet applied in industry, and we describe its main characteristics after defining what we mean by "organisation". Then we highlight roles of analysts who are not neutral in using event analysis method, assuming that these roles could be a block to progress of event analyses.

1. Introduction

One of the ordinary goals of high-risk industries is to operate in a safe manner. Industrial policy for fulfilling this goal involves, amongst others: safety oriented equipments design, relevant organisation (i.e. awareness of interactions needs between company Departments, of staffing quality and quantity requirement, of employees educational background, of training, of...), and compliance with regulations...

This set of measures cannot prevent occurrence of every event[2] and high-risk industries have to cope with some events. In order to learn from them, i.e. for preventing that the same or a similar event happens again, industries set up Operating Feedback System (OFS) as part of their safety management process. Methodology used by every OFS generally implies several steps: (i) detection, identification of event, (ii) data collection, (iii) event analysis – causes finding, (iv) definition of corrective measures, (v) decision-making regarding measures, (vi) implementation of corrective measures, (vii) assessment and validation of corrective measures, (viii) storage of information dealing with the treatment of this specific event, (ix) dissemination of information and lessons. Considerable resources are devoted by industries for running OFS. OFS is one of the pillars of safety management process as it is seen as an essential tool in the framework of prevention.

Nevertheless, numerous experts express concerns regarding limits of OFS. It is getting harder to establish convincing corrective action plans. Indeed, in spite of substantial efforts put for running OFS, the same human errors or series of similar technical breakdowns seem to recur (Dien and Llory, 2004). Once could say that, concerning safety, industries have reached a limit and are "*dancing tango on asymptote*" (Frantzen, 2004), meaning that numbers of annual safety records are either slightly higher or slightly lower than the ones of the previous year, but are more or less the same since several years.

Are we subjected to be satisfied with these weaknesses of current OFS? Does prevention have to find new paths? Some specialists implicitly reject event analysis and advocate either to analyse daily routine situation in order to figure out factors of operation strengths and reliability (e.g. Rochlin et al., 1987; Laporte and Consolini, 1991) or, at the opposite side of the spectrum, to be prepared to manage crisis because accident occurrence is inevitable (e.g. Lagadec, 1994).

Fundamental question is: what has to be reappraised? The whole OFS (Dechy and Dien, 2007; Dechy et al., 2008)? The implementation of corrective measures (Llory et al., 2009)? Event analysis itself or analysis methodology? Furthermore can we define analysis methodology only in terms of set of conditions to follow or to fulfil or can we extend definition up to role and features of the ones who applied the methodology? Indeed, could we consider that implementation of a methodology is "neutral" disconnected from, for instance, expertise of analysts, their position in the safety

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[2] By event we mean every type of malfunctioning with effects on either process availability or process safety: from minor and major incident to accident and disaster and also crisis.

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management process and/or self-interests of persons in charge of carrying out the analysis, the investigation?

After a brief description of analysis methodologies evolution grounded on a better understanding of what is an event, what is at stake when dealing with organisational dimensions of socio-technical systems, this article will provide a review of the current status and use of main root causes methods, their weaknesses in particular in the light of the methodological lessons learned from some accident investigations. On this basis, we will then propose a way to improve event investigation by the use of organisational analysis approach that we will define and will (try to) show how role of analysts[3] is as important as methodology used itself.

2. Evolutions of understanding of what is an event and what constitutes safety

Event investigations intend to figure out causes of event occurrence in order to define and to implement corrective measures for improving safety level of the system. As part of the safety management process, event investigation methodology is closely linked to the way safety-related concerns were taken into account. Reason (1993) described three periods regarding main focus of safety. Wilpert and Fahlbruch (1998) added a fourth one:

- *Technical period*: source of problems is technology.
- *"Human error" period*: source of problem is/are the person(s).
- *Socio-technical period*: source of problem is interaction between social and technical subsystems.
- *Inter-organisational relationship period*: source of problem is dysfunctional relationship between organisations.

These periods are "time-marked" periods, i.e. that vision of safety sources of problems has changed with time. This evolution can, for example, be seen in the nuclear industry.

Through the seventies, safety was mainly based upon technical reliability. Human Performance (i.e. human capabilities and human weaknesses) was not taken into account. Mitigation of potential or proven process failures resulted from technical changes and/or improvements.

During the eighties, after the Three-Mile Island accident, concept of "human error" has emerged. A positive effect is, that "the operator(s)" was (were) inserted in the loop of process operations. It allowed improvements in domains of human-machine interface, of operating procedures design, of training, ... During this decade, OFSs were set-up in order to promote lessons learned. We have to highlight that event analyses were operator-error oriented.

After the Chernobyl accident, during the nineties, concept of "Safety Culture" emerged. The safety culture of a company comprises the beliefs, behaviours, norms, and work practices of workers and management as well. Safety culture refers to what an organisation is like in terms of safety. This concept is of the first importance because it acknowledges, for the first time, that management activities are part of safety process – it means that managers could be seen, as the operators, accountable for occurrence of events. Nevertheless it is, to us, less operational than it seems. Indeed, according to International Nuclear Safety Advisory Group (INSAG) a safety culture could be ensured in a company: (i) if roles and responsibilities of everyone are clearly defined and known and (ii) if the relevant question is asked to the right person at the right time. In other words, "safety culture" can be seen as the willingness to work on behaviour through organisation (INSAG, 1991).

[3] This point is developed further (§ 4) but we would like to already emphasize the importance of the analyst in the construction of identification, interpretation and analysis of the event.

In parallel, especially thanks to Reason (1990, 1993, 1997), concept of *organisational event* "came into the world". It widens event analysis potential scope. So, this decade is moving toward a taking account of "Organisational Factors". From a conceptual point of view, "Organisational Factors" cover *Socio-technical* side and *Inter-organisational relationship* side as well.

Results of evolution we briefly described are cumulative, non exclusive – from "technical aspects" to "human factors" and then to "organisational aspects". No-one aspect has to be ignored in favour of another. This statement can be seen as the "*Onion skin theory*": Approaches (skins) are prioritised from the core to outside: (i) technical approach, (ii) human factors approach, (iii) organisational approach. Each approach gives results, and the whole set of results allows to have a better vision – a better understanding – of the (causes of occurrence of the) event.

3. Status and limits of current event investigation

3.1. Status of root cause methodologies

Several investigation methodologies have been developed for the last decades to address several tasks of investigations (Frei et al., 2003) and to address root causes and system failures in conjunction with the evolution of the vision of what is an event and what constitutes safety. Among them, some of well known and/or relevant are MORT, MTO, TRIPOD, SOL, CREAM, Accimap and STAMP. These methods are presented in few words hereafter:

- MORT (Management and Oversight Risk Tree) has been developed in the sixties (Johnson, 1973) and is basically a very detailed functional analysis of a generic safety management system (represented on a graphic logic tree). The tool is articulated with event causal factor analysis and barrier and controls analysis. It provides the opportunity to assess the level of adequacy of the tasks performances (on two levels: specific control activities and managerial support activities) that would be expected to prevent accidents.
- MTO (Man Technology and Organisation) analysis method is also articulating the events, the causes, the barriers but is presenting deviations to normal situation in its diagram (Sklet, 2002, 2004). Some checklists are provided to identify fundamental root causes in work organisation, work practice, management of work, change procedures, ergonomic deficiencies in the technology, communication, instructions and procedures, education/competence, and work environment.
- TRIPOD method is based on James Reason Swiss Cheese model and implemented the idea of latent failures rooted in organisation that sets conditions (such as weakened barriers) for later active failures (such as unsafe acts). The latent failures are related to 11 Basic Risk Factors (Groeneweg et al., 2010).
- SOL (Safety through Organisational Learning) was developed during the nineties mainly for the nuclear power industries (Fahlbruch and Schöbel, 2011). Its aim is to seek out event causes beyond technical failures and "human errors". SOL is derived from a combination of Reason's Swiss Cheese Model, on the one hand, and the socio-technical system approach on the other hand. Event contributing factors are classes of five sub-systems analysed from an interaction point of view: individual, team, organisation, extra-organisation and technology. In order to help application of the method, a computerised version of SOL (SOLve) was designed.
- CREAM (Cognitive Reliability Error Analysis Method) proposed by Hollnagel (1998), can be used for accident analysis ("human error" prediction as well). As this method is cognitive oriented, it is mainly focused on actions of single actors in taking action

several modes of potential controls: scrambled, opportunistic, tactical and strategic. Modes are organised into a hierarchy, i.e. likelihood of failure decreases from scrambled control to strategic control. Each mode is assessed against a rating of contextual work conditions called "Common Performance Conditions (e.g. adequacy of organisation, working conditions, availability of procedures, crew collaboration quality...).
- Accimap tool, (Rasmussen and Svedung, 2000; Svedung and Rasmussen, 2002) is a methodology aiming to address pro-active risk management with a system control approach. It is not a pure accident investigation technique or tool but is interestingly widening the scope of managerial factors to more systemic factors such as the regulation context and the relationship between control authorities and the company. It is providing a mapping actor and graphic tools to represent the influences that shaped the accident dynamic.
- STAMP (Systems-Theoretic Accident Model and Processes) proposed by Leveson (2004) is as Accimap based on system theory and levels of controls of the sociotechnical system. It interestingly distinguishes the development from the operation sociotechnical system and focus on the control of emergent properties as a result of the interactions between system components.

All these methods do address human and organisational factors and some of them address system failures. Every method enables to figure out root causes of event. Nevertheless, they seem to show some limits compared to the most thorough and exemplary accident investigations (see Section 3.2). Furthermore, these methods do not question requested organisational context of use, roles and characteristics of their users (see Section 3.3). Although, as noted by Sklet (2002, 2004), they require high level of tool mastering in addition to underlying competencies in human and organisational factors.

3.2. What can we learn from some exemplary accident investigations?

Indeed, a comparison between methods[4] used during exemplary accident investigations carried out either by independent inquiry team (e.g. Lord Cullen, the CAIB[5]), by experts board (e.g. the CSB[6]) or by social scientists on some major accidents[7] and the methods we briefly described in the previous section allows to figure out some of their weaknesses. In other words, it allows defining criteria and dimensions not taken into account and which could have helped to reveal quintessence of event(s) analyzed especially from an organisational point of view:

- These methods take poorly into account the "time aspect", i.e. "History" is not explicitly a dimension of the investigation. They do not go very far upstream in the history; they make inquiry begin (almost) at the time of the active failure, i.e. they go back few "steps" before the active failure to define sequence of events leading to the accident and/or to detect some latent failures. In that sense, methods as MORT or Tripod are more focused on results (events) rather than on (sociotechnical) processes leading to them. On the other hand, exemplary investigations go (quite far) back in time and they trace back phenomena of safety deterioration in the considered organisations. For instance, the CAIB went back to the launch of the first space shuttle, some 22 years before and the CSB looked at the history of the refinery before merger between companies BP and Amoco.
- These methods are mainly static and deterministic, i.e. they belong to the "cause ↔ consequence" paradigm with more or less direct links between cause(s) and consequence(s). They can poorly cope with complex – versus linear – phenomena, with feedback loops, overlapping phenomena, with postponed effects, with... while, for instance the CAIB assessed effects on the shuttle safety at the NASA of decisions taken at the White House and at the Parliament and the CSB showed influence on the accident occurrence of BP's confusion between occupational safety and process safety. Similar statements[8] are shared by Leveson (2004) but with a different proposal.
- These methods put forward overhanging analysis, i.e. proposing an expert's vision of the circumstances, of the causes leading to the accident. Actors involved in the event, from the field operators to the management are silent. These methods do not call upon actors to speak, although their living knowledge of the situation could be of great benefit for the inquiry as the CAIB showed when it made an in-depth analysis of the (no) decision making process during the 17 days of the space shuttle *Columbia* last mission. In other words the subjectivity of the actors is kept instead of being filtered towards objectivity standards.
- These methods, except for SOL, Accimap or STAMP, can poorly address inter-organisational issues and their influences on safety deterioration. We have to notice, for instance, that the CAIB analysed in detail relationships between the NASA and the political sphere and the CSB thoroughly interpreted flaws in decisions and actions of the federal agencies in charge of safety towards the BP refinery at Texas City. These statements are shared and recently led the developers of Tripod method (Groeneweg et al., 2010) to propose an "extended Tripod" to address factors that are beyond managerial control and will join the group of system approaches such as SOL, Accimap and STAMP [see also Sklet (2002, 2004) for levels of socio-technical system addressed].
- Finally, these methods are not designed for spotting some sociological and cultural phenomena related to safety and put in obvious place by some scholars as the "normalisation of deviance" (Vaughan, 1996), the weak signals (Vaughan, 1996; Llory, 1996), the whistleblowers, power issues, organisational complexity effects on communication flaws, production pressures balance with safety....

In spite of some industrialists' claims, we assume, thanks to available documents, that event investigations carried out by at-risk industries or their related independent institutions (e.g. transportation investigation boards as NTSB in the United States, BAA in England, BEA in France...), are still focused on technical failures and "first line" operators actions. When organisation is taken into account, it is mainly at a "first line" operators collective level (communication, coordination, cooperation...), operators being in the same team, or in different team of the same company or even in different companies. At best, some safety management system activities are analysed. To give an example, the US CSB carried tens of these investigations until 2005 Texas City refinery explosion

[4] Whether methods are explicit or implicit in the public reports.

[5] *Columbia* Accident Investigation Board.

[6] Chemical Safety and Hazard Investigation Board.

[7] Turner and Pidgeon (1997) on about a hundred of accidents, Perrow (1982, 1984) on Three Mile Island accident, Vaughan (1996) on the space shuttle Challenger explosion, M. Llory on several accidents and on Three Mile Island (1996, 1999) and Hopkins (1999, 2008) on Longford gas plant and Texas City refinery accidents.

[8] *"Social and organizational factors, such as structural deficiencies in the organization, flaws in the safety culture, and inadequate management decision making and control are directly represented in the model and treated as complex processes rather than simply modeling their reflection in an event chain. The use of control structures and process models in STAMP allows incorporating non-linear relationships reflecting the behavioural dynamics controlling the behavior of the entire technical and organizational structure over time."* (Leveson, 2004).

investigation for which they carried out a thorough organisational analysis.

Accident investigations carried out by independent assessment teams (e.g. Cullen, 2000; CAIB, 2003) showed that these types of methods did not allow going far enough. It led to the development of a specific accident investigation method we called "organisational analysis of events" (Dien et al., 2004). Furthermore design of a method cannot be disconnected from role and expertise of users. In other words, are those event investigation tools used on the field and by whom?

3.3. Status and limits of investigation practices and skills

Some years ago, the ESReDA Working Group on Accident Investigation (2009) (WGAI), (Valvisto et al., 2003; Dechy et al., 2012) found a rather low use of investigation tools within the 49 organisations in 15 EU/EEA member states that responded to the inquiry conducted[9] (by means of questionnaires and interviews).

It was found that, in 2001, 69% of the questioned organisations indicated the use of an internal accident investigation procedure, an instruction or a rule. An international or national procedure was only announced by 10% of the organisations. The majority of the organisations mentioned that they did not have any particular investigation method. A specific method was recommended by only 20% of the organisations, and half of them quote the cause-consequence method. It was mentioned 14 different names of methods, with 8 by only one organisation. The principal quoted methods were the fault tree analysis, human error analysis, probabilistic risk analysis, and root causes analysis. One could add that some of the methods mentioned by default were not even accident investigation methods. Some root causes methods (MORT, SMORT and TRIPOD), and human error analysis were mentioned by two organisations for each method. Organisational investigations methods were not mentioned. The inquiry also reminded us that regulations have a major impact on the decisions to undertake event and accident investigation, and on how to conduct investigations, being private or public actors.

A second issue supporting the use of investigation tools is the institutional status and in particular the organisational structure in which investigators or analysts are appointed and furthermore the criteria that are used. In 2001, the existence of permanent investigation entities (such as investigation boards) was announced by three quarters of the responders. These investigation boards function with permanent investigators and/or with a board supervision of consultants and contractors. Authorities and research centres usually create ad-hoc committees with safety specialists. Companies and the consultants more often appoint temporary teams with safety specialists, shop floor operators and managers. The principal criteria to be selected within an investigation team were: to be a multidisciplinary safety specialist, a specialist recognised in safety in general (ex: transport), an expert specialised on a system or sector (ex: ammonia installation), an expert on human reliability. A member of top management, local managers and event witnesses are also often part of the investigation team. We could note that, in 2001, the absence of qualified investigator and/or specialist in the accident investigation and learning from experience processes was frequent. Only nine organisations mentioned that being an expert on human behaviour and reliability would be a criterion for them to appoint an analyst.

These "depressing" results motivated the ESReDA Working Group on Accident Investigation to develop guidelines and recommendations at two levels: the first one, at a societal, institutional and legal level, on the public accident investigation issue (Roed-Larsen et al., 2005); the second one, at a methodological and organisational level, on the conduct of accident investigation (ESReDA, 2009). These results might seem a little old (almost 10 years) but we have not seen a lot of evidence to demonstrate a significant improvement (e.g. Okstad et al., 2012). As an example we can refer to the low rate and quality of internal investigations at BP Texas City refinery even for severe incidents such as loss of containment (US CSB, 2007; Llory et al., 2009). Among several remaining challenges to improve quality of accident investigations, one was to improve the training of analysts and another one was the implementation of organisational analysis. Our proposals are tackling and discussing those challenges.

4. Towards an organisational analysis of event

4.1. What do we mean by an organisation?

At this stage, it could be useful to define what the concept of organisation stands for us. Indeed, this object has several meanings and several authors use it differently. When organisation is taken into account, it leads to tackle several dimensions as: invariant elements set of actors, goal, rule, authority, role, communication system, coordination, co-operation, control... (Bourricaud, 1989).

Organisation can be described with different layers: from the team level up to the top management and corporate levels. Nevertheless, when the organisation is tackled in an investigation, its boundaries are poorly defined, i.e. its limits are often implicit for analysts.

When we use the "concept of organisation" in the "organisational analysis," we consider the whole company in its context, i.e. including external inputs as regulation, financial strains, political pressures and cultural dimensions... It means that we "*refer to the values, norms, beliefs, and practices that govern how an institution functions*" (CAIB, 2003).

We already said that when accident investigations refer to organisation, they often limit the focus to the team, shift level and sometimes to company's entities relationships. Our vision of organisation tries to be broader and more details are given in Sections 4.6 and 4.7.

4.2. Status of event investigation

If concept of organisational accident is already familiar to scholars, it is unfortunately, more recent in industry, and so not applied.[10] Indeed, similar statement was noticed by the Columbia Accident Investigation Board (CAIB) in its investigation concerning accident of the space shuttle *Columbia* occurred on February 1, 2003. The CAIB states: "*Many accident investigations do not go far enough.*[11] *They identify the technical cause of the accident, and then connect it to a variant of "operator error"* [...]. *When the determination of the causal chain is limited to the technical flaw and individual failure, typically the action taken* [...] *are also limited* [...]" (CAIB, 2003). As measures defined and implemented do not match "requirements" of the situation, a "similar" event is ready to (re)occur.[12]

[9] Main categories of responding organisations were authorities (27), industrial companies (15), research centres, universities and consulting (7) and were balanced across transportation sector and fixed installations. Five countries were totalling 75% of the responses: Sweden (11 responses), Norway (10), The Netherlands (6), Finland (5) and France (5): results could be impaired by a "Nordic countries bias".

[10] We do not say that investigations of event within the industry do not address at all human and/or organisational factors, but, only few investigations really go beyond technical aspects and "human error" paradigm and very few refer to a organisational analysis paradigm.

[11] Emphasis added.

[12] See for instance similarity between *Challenger* Space Shuttle and *Columbia* Space Shuttle accidents ("*Echoes of Challenger*" in CAIB (2003)).

The CAIB also points out a side effect of a weak analysis: "*Putting these corrections*[13] *in place leads to another mistake – the belief that the problem is solved*" (CAIB, 2003). As B. Turner said (Turner and Pidgeon, 1997), this kind of belief about the world and its hazards are *culturally accepted* within the organisation (i.e. the company). So, organisation will live, according to Turner's expression, an *incubation period* (Turner and Pidgeon, 1997): a period during which some events occurring will remain unnoticed because they are at odds with current beliefs about existing hazards.[14]

Nevertheless, some events were analysed from an organisational point of view: collision of trains in England (Cullen, 2000), loss of *Columbia* space shuttle (CAIB, 2003), accident in a plant manufacturing explosives (Lecoze et al., 2005), destruction of part of an alternator in a nuclear power plant (Dien and Hofseth, 2005), explosion in a refinery (US CSB, 2007).

What is currently at stake is to define organisational analysis features in a way it could be disseminated in industry culture.

4.3. Challenging the event chain analysis methodology

Currently, event analyses are mainly based upon an Event Chain approach. Event Chain Analysis methodology aims at directly "connecting" every single event to its cause(s). It means "in the other direction" that every action leads to direct consequence(s) and yet studies of accidents have shown that effects of some decisions (here seen as actions) are visible several years after they are made, and the way between decisions and consequence(s) is not direct (see for instance Vaughan, 1997).

Studies of accidents have also shown that factors causing an event are often interlinked, overlap each others. They can be present at the same time with effects of mutual strengthening or reduction (Dien and Llory, 2002).

Some scholars, as C. Perrow, argue that roots of an accident are embedded in the system itself and that ways taken for coming to, reaching occurrence of event are so complex (Perrow, 1984), that it is almost impossible to describe them by a "set of arrows joining (single event) boxes".

4.4. Main assumption

In-depth analyses of accidents, incidents and crises clearly showed that any event is generated by direct and/or immediate causes (technical failure and/or "human error"). Nevertheless their occurrence and/or their development are considered to be induced, facilitated or accelerated by underlying organisational conditions (complex factors).

A vast majority of events can be seen as the ending point of a process of safety degradation. An event is very rarely an "unexpected combination of circumstances" or an "act of God". Indeed, an accident happens at the end of an incubation period (Turner and Pidgeon, 1997), during which some events and signals (weak or strong) occur, but they are not perceived and/or not treated appropriately according to their potential threat to safety.

Every industrial system is coping with factors that impact safety, both positively and adversely. Life of an industrial system, from a safety standpoint, can be seen as continuous tension between resilient organisational factors (ROF) and pathogenic organisational factors (POF). An accident occurs when POFs overtake ROFs. Fig. 1 below portrays how events can be seen (with the medical metaphor) as symptoms of prevailing conditions (Dien, 2006).

4.5. To understand or to explain?

Goal of an organisational analysis is not necessarily to explain an event from an expert point of view resulting in list of (more or less numerous) direct causes leading to consequences (with, at the end the unwanted consequence). This approach brings some potential improvements in terms of, for instance, human machine interface, training, communication procedures (!!) ... Nevertheless, it leaves into shadow context of the event (i.e. a set a various phenomena as organisation adaptations, general and specific to the event decision-making processes, company beliefs and culture ...). Very often "explaining approach" is operator oriented and takes poorly into account managers actions (for instance "decision-making") and its role in occurrence of event – indeed, management actions have, generally, no direct effects, impacts concerning occurrence. In contrast, organisational approach tries to understand events in/by taking account of context and to highlight its relevant features (i.e. history, every implied actor, entities[15] potentially involved). It allows proposing corrective measures with broader effects. These measures are usually less "technical", and could be related to cultural aspects and it could take times before their effects are felt.

Purpose of organisational analysis is to understand how organisation is working: it leads to (try to) understand weaknesses, vulnerabilities, but also features of resilience of routine, day-to-day functioning.

4.6. Event organisational analysis main features

According to Reason (1997), a system producing an event is made of three levels:

- The person (having carried out the unsafe acts, the errors).
- The workplace (local error-provoking conditions).
- The organisation (organisational factors inducing the event).

Development of event is "bottom-up", i.e. direction causality is from organisational factors to person. In the event analysis, direction is opposite. "Gate" – starting point – of analysis is direct and immediate causes of bad outcome (event). Then, step by step, analysis considers, as far as possible, how and when defences failed.

In addition to results obtained by scholars in the field of organisational studies, real event organisational analyses carried out allow us to define the three main axis of an innovative approach, helping to go from direct causes to root organisational causes (Dien and Llory, 2006):

- Historical dimension (temporal aspect).
- Organisational network (transversal relationships between entities).
- "Vertical relationships" in the organisation (hierarchical relationships).

So an event analysis could be seen as a "journey" in the space defined by these three axes (see Fig. 2).

We have to note that, if these dimensions are introduced in an independent way, they are interacting and an analysis has to deal with them in parallel.

[13] i.e. fixing the technical problem and replacement or retraining of the individual responsible.

[14] Using a medical metaphor, we can say that if diagnosis (analysis) is weak (only deals with direct causes), associated treatment (corrective measures) will only treat the symptom(s), not the disease. For instance, patient's temperature will go down and virus is still potentially active. Furthermore as symptom is deleted, sick person (doctors and physicians as well) will think he/she is in good shape, while a virus is waiting to act again.

[15] "Entity" means a part of organisation more or less important in terms of size, staffing. It could be a small amount of people or even an isolated person (for instance a whistle blower).

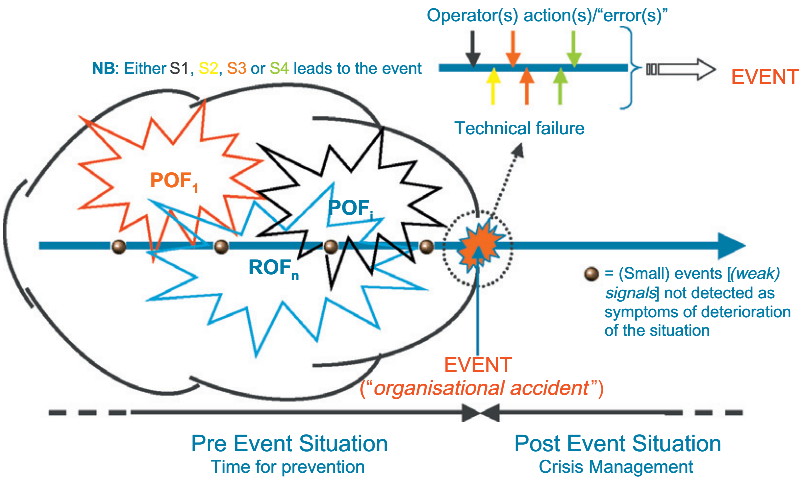

Fig. 1. Event development model (Dien, 2006).

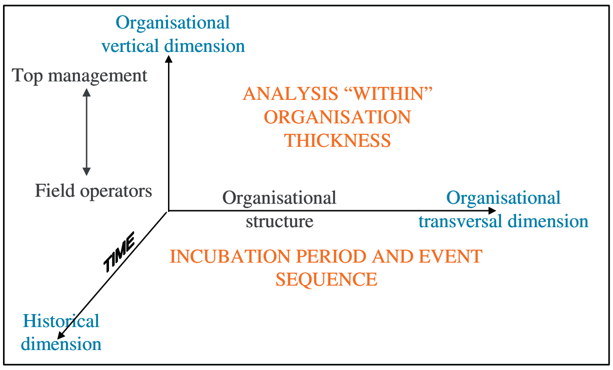

Fig. 2. Three dimensions to investigate (Dien, 2006).

4.6.1. Historical dimension

As Llory states (1998): "*accident does not start with triggering of final accidental sequence; therefore, analysis requires going back in time*, [...]" in order to put in prominent place deterioration phenomena. Analysis has to "go upstream" in the History of the organisations involved for highlighting meaningful malfunctioning aspects: what was not appreciated in real time has to "make sense" when risk was confirmed (i.e. when event has happened). Vaughan reminds (2005): "*The O-ring erosion that caused the loss of* Challenger *and the foam debris problem that took* Columbia *out of the sky both had a long history*". Early warning signs have to be looked for and detected long before time event occurrence.

We have to note that one chapter of the CAIB report (CAIB, 2003) is named: "*History as A Cause*". Few years before, Presidential Commission on the Space Shuttle Challenger Accident (1986) has entitled one chapter of its report: "*An Accident Rooted in History*". So taking account of past is important to understand the event. Goal is to go back in time for comprehending and analysing relevant processes and trends which led to the event. Numerous industrial events show that weaknesses of OFS could be incriminated for their occurrence – i.e. that previous relevant event(s) was/were not taken into account or poorly treated after their occurrence. Analysts have to pay a specific attention at incidents, faults, malfunctioning that occurred prior to the event. Analysts have to check how these past events could or should have brought relevant lessons that, if implemented, could have prevented this event.

Analysis of the "historical dimension" is parallel to detailed examination of parameters, of variables of context which allow understanding of events.

Analysis of the "historical dimension" has to avoid a "hindsight bias". Fine knowledge of event scenario – i.e. sequences of actions and decisions which led to it – allows assessing actual mid and long term effects of each action and decision. Analysts have to keep in mind that this evaluation is easier to make after the event than in real time. In other words, analysts have to avoid a blame approach.

4.6.2. Organisational network

Within an organisation, entities communicate: they exchange data, they make common decisions – or at least they discuss for making a decision, they collaborate ... So it is of the first importance to "draw" "*organisational network*" between entities concerned in the event. This network is not the formal organisation chart of entities. It is a tool for showing numerous and complex interactions involved for occurrence of event. It is a guideline for carrying out the analysis; it is built all along analysis itself.

Organisational network is hardly defined once and for all for a given organisation. It is drafted according to the analysis goals. Parts of organisation can be ignored because they were not involved in the event.

Organisational network allows visualising complexity of functional relationships between entities, and sometimes, it highlights absence of relationships which had to be present.

4.6.3. "Vertical relationships" in the organisation

This dimension is a part of organisational network on which a specific focus is needed. It covers *top-down* and *bottom-up* communications. It is essential to isolate it since it makes easier understanding of interactions between various management levels, experts and "field operators". We have to remind an obvious characteristic often forgotten during event analysis: organisation is a hierarchical system.

The main interests of this dimension are: modes of relationships, of communication, of information flows, modes of co-operation between hierarchical layers, ways power is exercised... Real events show that deterioration of these modes is cause of their occurrence.

At least, thanks to this dimension, causes of an event cannot be focussed only on field operators.

4.7. Some other concepts of organisational analysis

Organisational and structural features are of importance to understand the nature of Accident Analysis. However, we could also take other dimensions into account. Social sciences provide interesting findings to understand people's action in risky situations. Special attention has to be paid during investigations/analyses to two specific issues. They are not the only ones but seem of particular importance.

4.7.1. Weak signals

Notion of "weak signals" arose from Vaughan's work (1996). She defined a weak signal as "*information informal and/or ambiguous, so that threat to the flight safety*[16] *was not clear*". In other words, we can say that a weak signal is either a technical or a human or a social phenomenon which is not the direct cause of an event but which is meaningful regarding potential weakness, fragility of the socio-technical system in domain of safety.

4.7.2. Whistle blowers

Sometimes "whistle blowers" make the effort of writing to alert of a malfunction and express their concern for safety. These written exchanges occur among some operational staff-members, or their management, who sound the alarm about persistent malfunctions, the treatment of which falls to others, and they often underline the accident-generating consequences of these situations. These persons take their responsibility and also take risks through personal involvement, especially regarding their careers. Their objective is to reach the decision making centres in order to remedy the situation they are concerned with Llory (1998).

4.8. Some principles for applying organisational analysis

4.8.1. Field analysis

Even if an organisational analysis could hardly be carried out from documentation (having high quality), usually it is implemented through a field analysis with contacts with every actor (operators, managers ...) and with every entity (company where event occurred, safety authority "in charge" ...). In order to collect "true" information analysts have to have an empathic attitude toward people met during analysis,[17] and to ensure an understanding approach.

4.8.2. Background knowledge

"We only find what we are looking for"!!

An organisational analysis cannot do without a set of background knowledge related to methodologies, to main findings of organisational approach, to lessons learned from organisational failures. Indeed, as some root causes could be "hidden" in the past or by the situation, analysis is based upon assumptions to be confirmed or denied.

Background knowledge is a general framework for (field) analysis and is useful as well for making a synthesis and for drawing conclusions.

Knowledge of day-to-day operations (among which safety practices) is also part of background knowledge required for an organisational analysis.

4.8.3. A "thick" description of an event

First output of an organisational analysis is a "story" as detailed as possible which is, as said Geertz (1998), a dense description, a thick description of the situation having led to the event. For synthesis, story is expurgated in order to highlight on the one hand main technical and organisational processes "responsible" and, on the other hand specific organisational factors involved in the situation.

[16] She spoke about the Space Shuttle *Challenger* accident.

[17] Collecting "true" information does not mean to take what it is said as "holly words". Analysts have to understand speeches according to the context, the role of the speaker(s), ... Subjectivity is not banned by facts. It is more than complementary to "hard facts". It helps to understand how people made sense of the information they face and treat at the time they perceive it (see Weick, 2005). All these types of information collected have to be cross-examined as well.

5. Analysts and organisational analysis

5.1. Historical and sectorial developments of organisational analysis

The understanding and explicit formalisation of the human and organisational dimensions of events and safety came with public reports upon some major accident investigations and work of scholars (see chapter 3). It implies that the different industrial sectors (and in particular their analysts and the available methodologies) are at different stages of knowledge and practice of these new paradigms. Very recently, it seems that the CAIB report and posture constitutes a turning point on the organisational paradigm. This investigation has integrated some of the latest developments proposed by scholars, has used them explicitly and has criticised the approach in other investigations (too much focused on technical factors or human error oriented). This investigation is producing a "trickle down effect" on other sectors such as in the process industries with the US CSB investigation (2007) of Texas City accident and the CCPS[18] learning lessons process on the Columbia case. We can see here, the important role of independent safety boards and independent ad-hoc commissions in the development of this paradigm. Some analysts in those sectors and safety boards are now more familiar with those concepts.

5.2. Position of analysts within the organisation and epistemological barrier

It was shown by Rasmussen (1997) that several "layers" are involved in hazardous processes – Work, Staff, Management, Company, Authority, and Government. We assume that causes of an accident could stem from flaws in several layers. Event analysts usually belong to one layer. Their problem is to be able to detect and to take account of the whole set of event causes. For instance, the CAIB (2003) showed that "American political system" (i.e. the White House and the House of Representatives) played a role in loss of *Columbia* space shuttle in cutting down the NASA budget. This budget decreasing, with no parallel changes in the goals of NASA led to staff downsizing, time schedule pressure ... which weakened the "space shuttle system". Some root causes of an event could be outside of the company "affected" by it. Could an analyst or a team of analysts' members of a company, be able to detect such root causes or are they beyond their reach?

In addition "culture of efficiency" will lead analysts to emphasise on controllable and manageable causes (which echoes to developments led for Tripod extended, see Groeneweg et al., 2010) for which corrective measures are within the organisation boundaries analysts could reach. According to Hopkins (2003), analysts can be driven by "stop rules" in their investigation. Study of several event analyses reveal that often analysts implicitly halt searching causes to causes they handle, i.e. to causes for which they can propose corrective measures in order to prevent them. That means, for instance, if analysts belong to "management layer", they could "put aside" causes implicating "company layer" because decisions concerning corrective measures have to be made at the corporate level. That is a reason why, very often, analyses do not go far enough.

So, position of analysts within the organisation influences their vision of the situation and therefore their analysis. It seems that, in order to take an event in its broad scope, analysts have to be in position enabling them to catch the "big picture" of the event and to catch the comprehensive – organisational – situation prior to it.

[18] Center for Chemical Process Safety at http://www.aiche.org/CCPS/index.aspx.

Furthermore, position of the analysts towards the event, gives them implicit or explicit goals for the analysis. In other words, depending on position of analysts, results of analysis could be tremendously unlike each others. Thus, Hopkins (2003) shows, in analysing investigations carried out after an explosion in a gas plant in Australia, that results, and therefore definition of causes, were different according to the company owning the plant and according to the courts. In performing his own investigation of this event, Hopkins figured out a third set of results, of root causes having led to the accident.

In addition and at the basis also, Llory (1999), talked about an epistemological barrier for some actors, in particular with engineers, to think about organisational dimensions of accidents. The behaviourist model is still in mind to conceive the human factors despite the fact that they can refer to organisational and/or communication problems to explain some of the situations they face. And at the other end of the socio-technical system, the justice also often uses this underlying worldview.

5.3. Analysts as political actors

An event analysis could be summarised as series of decision-making (what is important, what to look for, what to take account of ...). Now, decision makers in any organisation "*are not perfectly rational individuals. They are collections of normal human being, constrained by common cognitive and organizational limits on rationality*" (Sagan, 1994).

Effects of organisation/company culture, self interests of analysts ... can have an impact on results of event investigation: "organizational blind spots can hide failures modes. Organizations often have taboo subjects which cannot be discussed,[19] because to do so hurts the morale and self-image of the organization" (Sagan, 1994).

Llory (1999) referring to M. Crozier analysing French failures of top decision making stated that: "Obstacles are not only epistemological and cultural; they are grounded on an organisational and hierarchical system that bans the accountability of executive elites".[20]

Does it lead to promote investigation carried out by "external" experts – in the sense not belonging to organisation/company affected by the event? It is not either the "pure" solution. Indeed external experts have also their limits to rationality. For instance, Sagan (1994) refers to a study made by Hawkins showing that safety "*inspectors tend to report problems only when they believe there is a good chance that they can win a case against the violators, rather than focusing on the actual effects on the hazards.*"

This goes back to the institutional status with independence as a political factor facilitating the tackling and explicit formalisation of those political factors (organisational, hierarchical, managerial, power, responsibility) (Dechy et al., 2012). However, there is no perfect situation as addressed by Bourdeaux and Gilbert (1999): the external (a priori more independent) person will have fewer difficulties to ask questions not asked by the insiders, and an insider could have the advantage of understanding the power relationships and the historical trends. A way of improving the whole situation is to protect the analyst, to institute the beneficial role of Cassandra's in high risk industries (Dien and Pierlot, 2006) and look for analyst with will not be complacent under contractual or hierarchical pressure.

5.4. Analysts and organisational data

Such organisational analysis requires specific methodological approaches, specific data and resources, to conduct interviews, to analyse collected data that are far from the resource allocation currently observed for incident analysis within industrial organisation. This is a reason among others why, those organisational analyses have often yet been performed by scholars, researchers and independent safety boards or commissions.

Furthermore, the access to the needed data is not that obvious. In this way, Llory (1996) highlighted this issue by titling one of his books: "*Industrial accidents: the Cost of Silence – Operators Deprived of Speech and Untraceable Managers*".[21] Indeed, the accidents are not described from the point of view of actors and the work of managers and experts is not enough deeply described in those analyses. The technical factors of accidents are politically more neutral.

Following an accident, the assessment of the real work of actors has to be performed but is hard to conduct. First, this assessment can be perceived as suspicious by actors due to the risk of use of information collected for allocating blame, finding a scapegoat and to assess individual performance of actors in human resources perspective (de Gaulejac, 2006). Indeed, it implies to address real work versus formal work which is a well known subject (Ombredane and Faverge, 1955; Bourrier, 1999). If analysts stick to the formal work, i.e. with a normative perspective, a secrecy culture can be established (Llory, 1999; Dejours, 2003). In addition, this access to real work implies to have access to tacit skills which is not obvious as stated by Dejours (2003): "*professional intelligence, in rule, is in advance on its knowledge and symbolisation*". Specific methodological approaches to collect data have to be practised, such as clinical approaches defined in social science. Analysts are also facing power dimension due to the strategic knowledge of the real work (Crozier and Friedberg, 1977) and individual or group "*defensive ideologies*" (Llory, 1999); Dejours, 2003) that can be observed when actors fear of allocation of blame.

5.5. Selection and training of analysts

Selection and training of analysts is an issue that will have to be strengthened in the next years as we have not seen yet many actions regarding this dimension. Organisational analyst competence can be seen at the intersection of two competencies: carrying out of accident investigation (and by extension learning from experience) and knowledge of human and organisational approaches of safety.

Although numerous experts are professionalised in the domain of safety, only few educational structures exist for training in "operational feedback" and in "industrial accident investigation". With the independent accident investigation boards, some developments are observed such with NTSB[22] academy. However the training proposed is still more focused on technical dimensions of investigations with forensics techniques for example.

Regarding human and organisational dimensions of safety, different industrial sectors, since the eighties, have selected human factors specialists, (ergonomists, psychologists...) in the frame of the "human error" paradigm. Very few industrial organisations have integrated more organisational dimensions experts (sociologists, expert in political science ...) for dealing with safety management, safety control and governance.

5.6. Transferring tools and methods on organisational analysis?

One of the issues that is underlying here is the gap between some knowledge of scholars, researchers, and experts in the field of organisational analysis and the industrial practices of incident analysis. An operational transfer of those concepts is lacking (Bourrier, 2004).

[19] Emphasis added.
[20] Of the country.
[21] Translation by the authors.
[22] National Transportation Safety Board (USA).

Some perspectives of developing framework, approaches, tools adapted to an industrial context with insights coming from lessons learned in organisational analysis have been proposed (Bourrier, 2004; Le Coze and Dechy, 2007).

5.7. Accident analysis: a social product and analyst sense making

As mentioned earlier, social sciences provide interesting findings to understand people's action in risky situations (e.g. Vaughan, 1996). This theoretical approach is worthwhile in terms of accident prevention, based on a posture of doubt, critical analysis of knowledge acquired and tools implanted. In echoes to Weick (2005), we consider Macrae's study (2007), as an interesting way to explore and operate this notion. He argued that ''*in modern, complex and hazardous organizations such as airlines, risks are rarely self-evident. They must be actively identified and interpreted, often in a context rich with weak or equivocal signs of potential problems*''. Risk managers and experts have to try to piece signs together in order to give sense to them. The capacity of analysts or safety managers to detect, interpret and take these early signs of potential problems lies in a posture of doubt; of learning from their own ignorance. In addition to the necessary a posteriori reconstruction of those processes, we believe that this approach could be of interest for investigations. Indeed, an issue to address is: how this doubt prone behaviour (gained during daily operations and a priori analyses) could influence analysts during an event investigation?

5.8. Analyst' judgement, memory of organisational analyses and culture of accidents

One of the crucial issues in organisational analyses is the judgement that arises after the thick description when dealing with findings. A posteriori, it is necessary to avoid both the retrospective bias and to avoid the '*retrospective illusion of fatality*' (Llory, 1996; Llory et al., 2007). The critical challenge is to be able to assess and judge complex factors, latent conditions and to detect an incubation period.

In both situations, a judgement as a conclusion of analysis is pronounced by the analyst. The judgement of complex factors (with feedback loops, non linearity, counter-intuitive effects ...) is not obvious, even after the event, and relies on underlying assumptions deriving from models of safety, on a modelling of the accident (thick description provided by organisational analysis) and on accident cases to support judgement. Indeed, the medical metaphor was used by Llory (1996) to explain the need for reference cases to judge potential pathogenic conditions or behaviours of dynamic socio-technical systems. Furthermore, to study organisational pathogenic patterns, Llory (1996), referring to S. Freund metaphor regarding dreams and unconscious, has recalled that accident investigations are the '*royal road*' (versus ''normal'' situations analyses) for understanding real organisations functioning. On this basis, we developed the idea that this knowledge of accidents should be learned and transferred into a Culture of accidents in order to help safety diagnosis (Llory and Montmayeul, 2010; Dechy et al., 2010).

6. Conclusions

It appears that use of organisational analysis for event investigation could break current limits of operating feedback systems and improve safety since potential causes of incidents or accidents are looked for in a wider scope than the one of analysis methodology generally used in industry.

One of the issues, for the methodological dimension, would be to work on closer bridges between scholars and industries. In spite of many in-depth studies on these issues, many scholars still regret that accident analyses are too technical and not deep enough. We could say that some efforts are still to be made by scholars to translate and transfer the intellectual and practical tools to the industries. This work requires taking industrial constraints into account – production, people's background, market conditions ... If scholars and researchers tend to be closer to industries concerns, bridges should be built in a more concrete and stronger way. This is in that sense that we keep on developing an organisational analysis approach (Dien et al., 2004; Llory and Montmayeul, 2010; Llory and Dien, 2010). It will imply also serious selection and training of analysts on those approaches.

Nevertheless, analysts either could not be able – i.e. to be in a ''wrong'' position within organisation – to address the whole scope or do not have self interest to extend scope of investigation. They could also face difficulties to have access to relevant organisational data and to make sense of it.

Furthermore, practical corrective measures have to be derived from investigation and have to be implemented. However, some corrective measures are out of sphere of competence and responsibilities of persons in charge of drafting corrective measures, and of persons in charge of decision-making regarding their implementation. So, main improvements concerning effects of event investigations have to be sought with future studies of position and role of analysts and of decision-makers regarding implementation of corrective measures.

One promising, but resource and time consuming, is to promote a ''check and balance'' approach for investigation, meaning a collective building of results deriving from several parallel organisational analyses. Results of each analysis could be compared and discussed in order to define one set of shared results allowing gaining a ''global vision'' of the event. This approach could be worthy for major accidents.

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