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Blind Managers, Systems Complexity and Weak Signals

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In our rapid and global society, the complexity of dimensions entering in accidental sequences (new and emerging Technology, increasing interdependencies between systems, external constraints, and societal concerns) imposes to consider industrial accident through holistic and interdisciplinary approaches. Several scientific studies have validated this approach with models describing these systems as socio-technical and complex (Reason, 1990, Rasmussen, 2000, Leveson, 2004). In this context, classical management tools adopting systems decomposition (risk analysis, reliability, technical and organizational barriers...) strongly reduce the probability of major accident. However, they meet several limitations, and major accidents still occurring the most cases, study of accidents shows us that systems degradation is often associated with managerial failures showing up through several forms (lack of control, communication problems, deficiencies in the management of change...). Consequently, technical barriers are gradually losing their efficiency and systems safety performances are decreasing. In this process, tension is extreme in the resilience of systems, causing an intermediate phase of resistance, announcing the rupture. In these conditions, some particular operating phases (temporary period, maintenance shutdown, restarting) can no longer be contained until the major accident. This is during the period of crucial resistance that the system sends the most representative symptoms. This kind of precursor signals, known as weak signals, is broadly described in the literature. In this context, how to deal with the complexity of systems, and gather weak signals shown by organizations, to anticipate major accident? Our research question is the following. The literature demonstrates the existence of weak signals, and their relevance as accident precursors. Why these signals have not been taken into account? Our work should help to analyze the rupture between resilience and resistance and find the weak signals in organizations. Our study is based on the methodology of case study.. As result, our study enabled us to identify several filters that have hidden weak signals in organizations. Development of automatization, management focused on standards, involvement of stakeholders increasingly numerous, and economic issues freeze the intuitive perception of the system by the manager.. It is now in management systems that we must seek the weak signs of an announced catastrophe.

Research field: Risk Management

Introduction

Classic management tools based on systems decomposition (risk analysis, reliability, technical and organizational barriers) strongly reduce the probability of occurrence of a

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major accident. However, this approach meets several limitations. Industrial accident shows now a dynamic and systemic nature, which limits efficiency of safety management systems. Exceptional and unlikely, accident is surprising and disconcerting. In this way, and faced to the surprise, the course of events is unexpected and unimaginable. The link between causes and effects is broken, and the consequences due to the interdependence of the industrial system and its environment are global and major. These difficulties to describe and explain the occurrence of accidental phenomenon have been highlighted during recent technological accident, such as loss of the shuttle Columbia (CAIB, 200X), the explosion of the Texas City refinery (Mogford, 2005), and the nuclear accident in Fukushima (Department of nuclear safety and security, 2011).

In most cases, analysis of accidents shows that the degradation of system is often associated with a lack of consistency in sustainable management. Under these conditions, some particular operating phases cannot be contained, and lead to a major accident. Also, it was during the crucial period of resistance that the system provides the most representative symptoms. These signals emerge at several levels, from operational to managerial level. They also emerge more or less early, several weeks before the event, until the beginning of accidental chain. If their existence is proved, it is necessary to question the absence of their consideration. The study of the explosion of the Deepwater Horizon oil rig shows that several filters prevent consideration of weak signals. Increasing automation of production processes, management focused on standards, involvement of stakeholders increasingly numerous, and high economic stakes paralyze intuitive listening by manager. In our approach to support decision-making, we are interested by the managerial and very early signals. Consideration of this information should enable a decision of prudence (for example the slowing or cessation of activities). However, this knowledge is heterogeneous and dispersed in the organization, preventing collective learning necessary to anticipation. In this context, how to deal with the complexity of the systems and bring these weak signals in the organization to anticipate the major accident?
This article will proceed according to the following plan. The first part will discuss the theoretical perspectives about weak signals. A second part will explain the reasons that led us to select the sinking of the Deepwater Horizon as a case study analysis, and the method used. A third section will describe the causes and contributing factors of this accident. Finally, the fourth part will discuss on the presence of weak signals in the organization before the accident, and various filters that have prevented their consideration.

Theorical Perspective about Weak Signals

According Saltmarsch et al. (2012), weak signals have two dimensions: causality and temporality. Causality indicates whether an event that precedes an accident is part of causal chain (the failure of a component, for example), or if the event is simply correlated to the accident (when an animal just leaking before an earthquake). Temporality indicates whether an event is identified as a weak signal a priori, or as a precursor signal in a post-event analysis. The process of identifying and taking account of weak signals is implemented on three levels of the system: the individual, the local organization and the industry. Effective management requires an investment at each of these levels. Hiltunen (2008b) adds three-dimensional features of the signal. The first dimension is the *object*. This is the reference: a future event. The second dimension describes the *representamen*. This is the concrete form of the signal (rumor, image, special event). The third dimension is the *interpretant* which is basically the meaning of the signal and its ability to imagine a

person's future situation. At these dimensions, Hiltunen (2008a) defines several conditions for weak signals: a support vector, critical mass, and dedicated actor. The concept of critical mass was also developed by Lesca et al. (2002). The weak signal comes from its informative potential. It must exceed a certain threshold of interest to be heard (Mevel, 2004). The threshold concept was already apprehended by Bliss et al. (1998) in the field of safety. However, the problem of interpretation of the signal and its consequences is more difficult in the field of safety. Lesca et al. (2002) identifies several characteristics that define a weak signal: its fragmentation (complete or incomplete), visibility (among other information), its meaning (ambiguity, obviously), familiarity (information already met), its value and persistence (meaning over time), relevance (in a given context), and reliability.
The concept of signal is embraced by the literature, but it is also questioned. Moijanen (2003) criticizes the lack of consistency in the definitions of weak signals. The only one feature commonly accepted by experts is the role of the weak signal as first possible sign of a future change. There remains confusion about the following characteristics: the relationship with transitory phenomenon, duration, subjectivity, and the person interpreting the signal. Pitkänen also criticizes the choice of the concept of signal. Signal requires a transmitter and this one is missing (Pitkänen, 2006). According to Rossel (2012), the concept of weak signal is a metaphor and remains to be defined. The process by which an element of context is transformed into useful information for the individual or organization is not scientifically supported (Rossel, 2012).

Application of the concept of weak signal in organizations is also questioned. Organizations may have legitimate reasons to ignore weak signals, especially if the information seems vague and unfounded (Aven, 2011). The interpretation of the signal can also pose difficulties. A past near-miss can be interpreted by the company as the success of the safety barriers, rather than as an alerting signal of problem (Paté-Cornell, 2004). The organization is facing a myopia that does not allow it to get out of the problematic situation (Rossel, 2012). The reporting system also plays a role in the management of weak signals. It may cause a bias of reporting, which doesn’t allow the manager to distinguish a precursor trend reported and a true underlying trend.

Finally, Amalberti gives three reasons explaining the lack of consideration for weak signals in organizations. First, the interpretation of weak signal is rejected on a rational basis. An incident impacting a minor issue regarding risk assessment will strengthen this risk assessment. Second, the posture adopted by the whistleblower lost credibility of alert. Third, analysis of weak signals requires more complex analysis models (model conditions, percolation, which associate in the same context signals and minor events) that conventional risk analysis, and require time, resources, and scientific background (Amalberti, 2013).

Methodology

Given a real case study being the deepwater Horizon sinking, our analysis has two main objectives. The first one is to highlight the anterior events we believe were weak signals and the second is the understanding of the reasons laying behind their non consideration by the management.

Firstly, it is worth discussing the criteria justifying our selection of the Deepwater Horizon accident: Gravity of consequences : explosion caused the death of 11 peoples, important economic losses (infrastructure, investment relating to the exploratory

phase), and a major environmental disaster (Deepwater Horizon study group, 2011) ;
- Temporal proximity of the event : allows to focus on a technology still used, with materials of analysis stabilized ;
- Technology implemented: the drilling of deep-sea is a technical challenge (high pressure, high temperature), in a dynamic and aggressive environment (related to sea conditions). These high-risk conditions require strong operating constraints and a high level of control of the process ;
- Industrial activities in development: technological progress allows exploitation of new oil reserves. Deep-sea drilling activity, and therefore the need for knowledge of industrial risk management, tends to develop in the future.

As part of our analysis, materials come from primary and secondary sources (Yin, 2008). Several types of sources were used:

- Post-accidental reports :
    - The bureau of ocean energy management, regulation, and enforcement. Report regarding the causes of the April 20, 2010 Macondo well blowout. United State department of the interior – 2011.
    - Deep Water, the Gulf oil disaster and the future of offshore drilling – Report to the President – National Commission on the BP Deepwater Horizon oil spill and offshore drilling – January 2011.
    - Final Report on the investigation of the Macondo well blow out – Deepwater Horizon Study Group – March 1, 2011.

- Audiovisual documents :
    - Deepwater Horizon - Exhibits & Transcripts : http://www.uscg.mil

BP accident report has been removed from the study. Independence of inquiry has not been demonstrated. Our method, based on the study of indirect evidence, may admit some limitations. If data issued from official reports can be considered as credible, reliability of secondary sources may be difficult to establish. To ensure data reliability, two precautions have been taken. Firstly, we consulted documents from official sources (investigation report from institutional source for example). Secondly, overlap has been performed between multiple secondary sources.

The Deepwater Horizon Sinking

Contrary to conventional well, for which the technology is mastered, deep-sea well have characteristics that constitute a technological challenge. In this context, operators have little data on the geological characteristics of the reservoir and surrounding formations. It’s a high-risk drilling process.

1. Sequence of Events

An industrial accident is the result of a chain of events, which can be represented by the model of Reason (Reason, 1990). As indicated in the investigation reports, the explosion took place during the temporary abandonment procedure of the well.
- On 20 April 2010, 0:36 am, cementing of the well is completed.

- Around 11.00 am, positive pressure test is carrying out. This test is done 10 hours after the end of cementing phase, contrary to the contractor requirement (48 hours).
- 11.30 am: mud displacement procedure is reviewed by the personnel. Despite some significant concerns, agreement is given to follow the procedure.
- Around 1.30 pm: the rig starts the mud offloading. Operator expresses some concerns, because several operations are realized at the same time. Mud flow cannot be followed precisely.
- 3.56 pm: negative pressure test is carrying out. Results are difficult to interpret, due to the simultaneous offloading and cleaning activities, on the rig.
- 5.00 pm: operators find an imbalance pressure into the well. The pressure at the bottom of the well is less than that present in the geological layers. Operators also seeing a mud rise, indicating a leak. Despite the actions taken to stabilize the well, the pressure is multiplied by five in some minutes. A debate between the operators to understand current events occur, and leads to carry out again the negative pressure test.
- 5.30 pm: second negative pressure test begins. Pressure into the well rises and falls quickly, and then stabilizes at high level. Around 8:00, the result is considered positive, despite high pressure into the well.
- 9.00 pm: operators conducting final tests. As in previous tests, simultaneous operations prevent an accurate reading of the stream flowing into the well. Tests are considered as successful and led to carry on the abandonment procedure.
- 9.30 pm: the well undergoes several sudden changes in pressure. To 9:40 p.m., oil overflows the well. Despite operators' attempts to regain the well control, oil spills on the rig. An explosive atmosphere is formed, reaches generators, and explodes.

2. Organizational Factors of the Deepwater Horizon Explosion

Organizational dimension in the analysis of accidents have strongly emerged after the explosion of the shuttle Challenger. Regarding the Deepwater horizon accident, several factors relating to the organization and management has been identified as contributing factors.

2.1. Cost Cutting and Production Pressure

Operational teams working on the Deepwater Horizon were submitted to daily production pressures. Each operator was aware of the additional costs generated by suspensions or delays in the drilling process. This pressure led operators to make compromise on preventive measures, especially on barriers they did not consider as necessary. Thus, the responsibility of cost cutting had fallen to the lowest operational level. This dynamic has resulted a reduction of investment in the risk control, and removing safety barriers deemed useless, but necessary to keep control of the drilling process. Several signals show the imbalance between the operators' performance required and the necessary operational safety measures:

- The presence of incentives to complete drilling operations as soon as possible and reducing costs. The project was already 50 days late and $ 100 million over budget.
- The unplanned decision to transform the exploratory well in operating well, to reduce the time and costs required for the subsequent completion of this step, and allow a faster return on investment.

- The focus of management on competitiveness and performance improvement.
- Ability to meet budgets and reduce production costs during the annual personnel evaluation (in 2009 this was the case for 12 of 13 peoples involved in operations in Macondo).

2.2. Personnel and Management Issues

During the weeks that preceded the accident, operators were confronted with several organizational changes. These functional and hierarchical changes, by impacting the roles and responsibilities of various managers, have deeply affected the management system. If these changes were justified to meet a functional need and manage a relational conflict between two managers, they also had a negative impact on the operational level:

- Monitoring problems of following drilling process, especially during critical phases: cementing the well, implementation of the temporary abandonment procedure, implementation experience feedback on recent well incidents.
- Frustration among managers who have reduced quality of communication during the drilling process.
- Additional delays in affirmation of leadership and authority, impairing the decision-making process.

Several factors indicate the difficulties caused by organizational changes:

- The day of the accident, nine employees with responsibility in drilling operations had less than 6 months experience.
- During the weeks preceding the accident, several documents and statements from the personnel indicated concerns relating to organizational changes, especially in the roles and responsibilities of managers.
- In March 2010, the second loss of control of the well has generated tensions between several managers, formalized by email.
- The day before the accident, concerns were expressed about the consequences of the transfer of personnel made a few days ago, and managerial last minute changes.

2.3. Rules and Procedures

Several catastrophic failures have emerged as the result of multiple violations of regulations and operational standards. Failure to comply with recommendations related to drilling operations resulted in a weakening of the well structure. Losing his physical integrity well was not able to hold strong hydrocarbon pressures encountered during drilling. Several situations reflect weaknesses in the working procedures:

- There was no procedure for implementation and interpretation of negative pressure test. No standard has been designed and provided for the interpretation of test data and prescription of corrective actions to be implemented in the absence of certainty on success. However, this test has been performed at high risk with a minimum level of safety barriers.
- The results of the first test negative pressure led to several minutes of deliberation between operators. Given the diversity of interpretations, they agreed to conduct a second test. This has been validated, despite strong pressures found into the well.

- Contractor who has designed cement has expressed concerns about a high probability of failure of cement if less than 21 centralizers are used. Only six centralizers were set-up.

To these technical failures, gaps added in the implementation of safety barriers. These have remained ineffective in preventing the occurrence of dramatic consequences in the loss of control of the well. We can indicate following gaps:

- Deactivation of the flow indicator during the transfer of drilling mud. This indicator is critical for the detection of loss of well control.
- Configuration of the general alarm system on the "inhibited" mode. When this mode is activated, the detection of several explosive clouds in several areas of the platform does not automatically activate the general alarm.
- Emergency disconnection system from the well was not scheduled to occur automatically upon detection of an explosive atmosphere.
- Lack in "stop work" implementation. This procedure, in which every personnel are involved, oblige the operator to stop any activity to prevent the occurrence of an accident. The investigation clearly identifies several situations in which the "stop work" should have been asked.

2.4. Communication

Within the organization of BP, the process of communication and decision-making is based on explicit procedures. However, significant communication problems were present in the weeks before the accident. These issues concerned horizontal (between contractors) and vertical exchanges (between managers and operators) of the organization. Various problems of communication were identified:

- During negative pressure test, operators have not asked advice to BP managers, more experienced in the interpretation of results, and despite their doubts.
- A few days before the explosion, an accident seriously injured an operator. This incident has been added to previous accidents. Given these safety concerns, it was decided to take regular breaks to minimize operator fatigue and the risk of accident. There is no evidence that these breaks were made.
- The day before the accident, BP personnel on the ground did not pass some critical information to the onboard personal, about the drilling and well cementing.

2.5. Mechanical Integrity

The analysis of the sequence of events shows occurrence of several technical failures of safety-critical systems. The consequences of these failures have been important because they occurred during a critical phase of drilling operations. Emergency systems did not run correctly, and an explosive atmosphere has been generated. These failures have several origins, related to system design and maintenance:

- Engines of the platform have been programmed to stop automatically in case of overspeed. This mode "rig saver" has not been engaged, allowing the ignition of the explosive atmosphere.
- Engine rooms number three and six were classified as not subject to explosive atmospheres, despite their proximity to the wellbore.
- The BOP has met several failures in automatic and manual modes, which could prevent the well closure.

- The design of the monitoring system allows the reading of "false positive" as test results of pressure.

2.6. Management of Change

In the organization of BP, process of risk analysis and management of change have been implemented. However, they have not been properly executed. As a result, the drilling team has been faced to multiple and simultaneous operations conducted in critical times, without taking into account the interference between them, and based on an inappropriate assessment of risks. These lacks have seriously compromised the safety of the system. Several symptoms related to risk analysis and management of change were identified:
Regarding the risk analysis:

- Operators' training to risk analysis was based on the matrices probability / gravity. However, this training is not suitable for risk analysis of complex systems.
- No documentation indicates references or methods on how risk is evaluated on the platform or the ground. In most cases, the probability of occurrence and severity of the potential consequences are based on unsubstantiated impressions. The documentation does not indicate who has the skills and experience in risk analysis and management of complex systems.
- The decision to transform the exploratory well in production well has introduced new risks not taken into account initially. These risks are related to geological conditions, and the choice of cementing the well.
- Authorization for the Macondo well indicates that BP defines the probability of a blow out as insignificant. A prevention plan was not required, and it was canceled.
- Evidence indicated that no member of the crew, support team, or regulatory agency have already experienced a major accident such as that experienced by the platform.

Regarding the management of change:

- In the few days that preceded the accident, several last minute changes relating to procedures and personnel necessary for the preparation of the well occurred.
- The well abandonment procedure was implemented in parallel with several other activities. This has generated distraction for operators who could not properly monitor the events of the well, including indicators of drilling mud (volume, pressure).
- Procedures to move the fluid, carry out the negative pressure test, and clean the tank of the vessel were performed simultaneously. The sludge level in the tank was flying constantly, making the behavior difficult to observe well. The monitoring data was not reliable.
- The transformation of the exploratory well in production well led BP to deviate from the procedure originally approved by the MMS, which provoked the modification of several parameters: depth of the second barrier, interventions: mud displacement, types of pressure tests...

Filters That Hidden Weak Signals

The study of the Deepwater Horizon accident confirms the existence of weak signals. Symptoms of the system drift were present in the organization before the explosion. Consideration of these precursors could have allowed anticipation of a major accident.

These weak signals were of various natures. Some were relative to management: the number of days of delay, the recurrence of well events, or reorganization of staff in a critical phase of drilling. Other signals, more operational, are less interesting for our study. Examples are the number of centralizers used, the residual pressure observed in the well after the tests, or the inability to monitor the flow of drilling mud effectively. Our case study also allowed us to see that these signals were related to all aspects of the system involved in the control of industrial risks: risk analysis, management of change, production pressures, leadership and management, communication, compliance with technical standards and safety procedures, communication, design and maintenance of well equipment.

If pointing out the existence of weak signals present in the organization before the accident is interesting, we highlight the question of the absence of their consideration. The Deepwater Horizon case study allows us to identify several filters that have masked the weak signals, preventing their consideration.

First filter identified is the technology. Deep-sea Drilling requires the use of advanced technology, emerging and increasingly automated. In this technological sphere, human, who is the designer of the system, is repositioned in its daily operation. However, it is undeniably the resort in case of crisis. It is the loss of control of the process by the machine and uncoupling of its automation. His intervention is then located on an unplanned and disturbed situation. It was the case during many unexpected events at the Macondo well, particularly during the well pressure test. Decision-making process is under strong time pressure, and action takes place on unusual interaction and disorder. On the Deepwater horizon, incapacity to determine the pressure test results led to numerous discussions between engineers and managers. Finally, operator is overloading in term of data and information. If information systems structure the decision-making process, and reduce the range of uncertainty, continuous flow generated forwards the moment of decision. Technology encloses the decision-maker in a pre-oriented environment through imposing a predefined representation of the system. For example, system ensures realization of a risk analysis, without considering the conditions of implementation.

Second filter identified are standards that are required for the system. The standard and its maintenance (audit, review ...) are different layers that focus the manager on economic, juridical, or environmental issues, and taking the risk away. On the Deepwater Horizon, managers had to feed a large number of reports and procedures related to the technical and environmental authorities, the labor legislation, drilling operations, corporate hierarchy, stakeholders... As a result, attention was focused on official and recognized risk criteria, but based on a limited view of the system. Manager is blind to variables not present in the normative reference field. Weak signals, non-standard but significant, are not taken in account. Thus, limited resources and predetermined situational analysis don’t allow early accident anticipation based on weak signals. These standards generate a gap between an artificial representation of system safety, and the real level of risk of the system.

Third filter is related to the large number of stakeholders involved in high-risk processes. 15 companies and organizations were involved on the Macondo well drilling. Accumulation of multiple stakeholders and experts in the management of the system leads to additional communication needs and information flows. This has resulted in a fragmentation of knowledge across all stakeholders, and has impacted efficiency of the decision-making process. These are not only slow-down, but cause dissolution of the responsibilities associated with decisions. Manager, surrounded by experts, defers his responsibility on the opinions expressed during the discussions.

The fourth filter identified through the case study is referring to the important stakes connected to the industrial processes. Deep-sea drilling activities represent huge financial issues, which are stated in operational performance, time scheduling, cost reduction, and low payback period. Strong impact of another further delay on the drilling did not allow managers to adopt a position of prudence. The presence of important issues doesn't allow getting out of the theoretical planning and constraints the decision. Intuitive perception of the system is clamped, preventing the necessary breaking decision to anticipate the disaster. An example of the impact of these issues is the possibility for the operators of the platform to remove preventing barriers deemed unnecessary. However, this attitude doesn't mean irresponsibility. The operator removed barriers due to a false representation of the situation, in which major accident is unlikely. The notion of safety compromise is therefore closer to how operator perceives risk.

Classical tools used to manage industrial risk prevent accidents in the most situations. However, in the few remaining cases, another approach is needed. The previous case study shows us that information was available within the organization, symptoms of accidental dynamic. Taking account these weak signals may have avoided the explosion of the platform, and the subsequent catastrophic consequences.

In the phase of system's resistance, the decision-making process and the manager have to be protected. The resistance appears through a variety of weak signals (technical, management, communication…), in the whole organization. A systemic approach is necessary to take into account these signals. It's a good opportunity to improve accident prevention by developing intuitive perception of managers.

Conclusion

Industrial accident is materialized by the sudden rupture. However, this crisis is rooted into the risk management. When he is making a decision, the manager validates weak signals and makes the crisis official. But this decision is made in a degraded situation. Our analysis shows the existence of filters that hide weak signals, preventing the adoption of a position of prudence. Increasing automation of production processes, management focused on standards, involvement of stakeholders increasingly numerous, and economic issues block weak signals, symptoms of the crisis to come. Our study is founded on one case. Several possibilities could improve our analysis. Most sources used, although valid, are only indirect information. Some reports may have some biases, inherent to the person conducting the interview. In addition, we have to relativize weak signals, in comparison to the classical tools of risk management. Intuition and weak signals, while important, is not enough and must be supported by a risk analysis and management methods. Also, if the presence of weak signals is demonstrated, it remains to develop practical tools for implementation. It's also necessary to incorporate a reflection on the role of whistleblower in the system. Weak signals are not only interesting for anticipation; they also provide a concrete and dynamic measurement of the level of risk management. They act as a counterweight to the risk analysis, albeit static and scenario-limited, but foundation of industrial risk management.

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