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Organizing learning processes on risks by using the bow-tie representation

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Abstract

The Aramis method proposes a complete and efficient way to manage risk analysis by using the bow-tie representation. This paper shows how the bow-tie representation can also be appropriate for experience learning. It describes how a pharmaceutical production plant uses bow-ties for incident and accident analysis. Two levels of bow-ties are constructed: standard bow-ties concern generic risks of the plant whereas local bow-ties represent accident scenarios specific to each workplace. When incidents or accidents are analyzed, knowledge that is gained is added to existing local bow-ties. Regularly, local bow-ties that have been updated are compared to standard bow-ties in order to revise them. Knowledge on safety at the global and at local levels is hence as accurate as possible and memorized in a real time framework. As it relies on the communication between safety experts and local operators, this use of the bow-ties contributes therefore to organizational learning for safety.

Keywords: Aramis method; Risk analysis; Bow-tie diagram; Organizational learning; Experience feedback process

1. Introduction

The purpose of this article is to present a possible way of managing risks by utilizing and, in a certain way, completing the Aramis method. We aim in fact to describe how bow-ties constructed, thanks to the Aramis method [1–4], can contribute to organizational learning for safety. We build our article around the presentation of the applied use of bow-ties in a Sanofi-Aventis production plant [5] and also on research work undertaken by the Ecole des Mines de Paris (EMP) on organizational learning and experience feedback [6–8].

We will first present the industrial context the method was implemented in. We will then quickly describe the main points concerning the bow-tie representation of incident and accident scenarios. The first chapter will end with the presentation of the theoretical bases of organizational learning in general and for specific safety aspects.

The second part will be the description of the practical use of the bow-ties to learn from experience from studies carried out within Sanofi-Aventis. The third chapter will make the link between this experience feedback loop and organizational learning properties described in the second part. We will finally conclude on the perspectives of the use of bow-ties for the organizational learning for safety and especially some extensions that can be envisaged.

1.1. Industrial context: answering the need of continuous progress for safety

Sanofi-Aventis is a pharmaceutical company founded in 2004 by the merger of Sanofi-Synthélabo and Aventis. Its scope of activities covers research (drug innovation and approval), primary production (active pharmaceutical ingredients production), secondary production (drug formulation and conditioning) and commercial operations. The method

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we present in this paper was implemented and tested in an Aventis plant of the primary sector before the merger of the two companies. However, the purpose is for this method to be adapted and generalized to the other sectors of Sanofi-Aventis depending on the improvement it allows.

The active pharmaceutical ingredients division counts several plants in France, in Europe and even worldwide. Some of them are Seveso II sites but they all possess a risk management system based on corporate directives. Safety is therefore integrated in everyday situations, thanks to procedures and management tools, but also thanks to a certain level of safety culture that can be observed in workplaces [9,10].

Continuous progress in safety was historically made possible with the generalization of accident investigations and with the implementation of risk management tools (safety audits, process safety analysis tools, MSDS databases, etc.) integrated within coherent safety management systems. The next step of progress seems now to depend on the appropriation by people of the risks they may face at work. Possibilities of progress seem therefore to rely on training and communication, which explains the strong collaboration between Sanofi-Aventis and Ecole des Mines de Paris in the area of organizational learning [11–13].

EMP's contribution to the Aramis project was inspired from this description of risk management activities. As a matter of fact, the Aramis method is designed specifically for anticipating incidents and accident scenarios. The identification of major accident scenarios, the construction of the bow-ties and the calculation of the three indexes (severity, vulnerability and management efficiency) contribute to the preparation of the system to face risks [1–4]. The exhaustiveness of Aramis bow-ties (four levels of faults and events) allows the identification of weaknesses and strengths of the industrial system at a given time. The localization of an event on an incidental or accidental sequence is then possible.

EMP has tested how groups of people could organize themselves to be more vigilant and able to improvise depending on what they may encounter, thanks to the bow-ties. A simplified version of bow-ties (at the most two levels for fault and event trees) was then used as communication tools helping each person working on a specific critical event to have a clear vision of its immediate causes and effects. These simplified bow-ties could be completed by other information (emergency plans, experience feedback, etc.) on the same sheet contributing to an efficient communication on critical events. In their simplified form, bow-ties can therefore contribute to vigilance and improvisation because they can be shared among people and also quickly updated.

EMP has tested this approach in several organizations within several transportation companies in France (subways, highways and airports) and pharmaceutical companies, such as Sanofi-Aventis [5]. We especially analyzed how the bow-ties were used and adapted to allow learning from incidents and accidents. We only present the results issued from our work in a Seveso II plant of Sanofi-Aventis because they are the nearest to the application area of the Aramis method. We will analyze how bow-ties are used as the starting point of a "learning from experience" loop. We will then show how they contribute to organizational learning for safety. This will allow us to discuss of possible extensions for the bow-ties used in an experience feedback process.

1.2. Bow-tie representation for risk analysis

The bow-tie representation is based on the coupling of a fault tree and an event tree linked to a critical event that represents a threat for a product team. Bow-ties allow the identification of safety barriers implemented to prevent the critical event from taking place and/or to mitigate its effects. Preventive barriers therefore mitigate critical events and protective ones mitigate their consequences. Several levels of causes and effects can be described, depending on the level of details that is expected. Bow-ties are therefore an interesting representation of defense-in-depth [14].

Safety barriers are located between sequence links. Knowing these links allows the definition of the barriers that are to be implemented in order to reduce the occurrence or the gravity of a risk represented by the critical event. Safety barriers can be technical or/and behavioral.

Strengths and weaknesses of the system exposed to an accident depend on barrier efficiency. An accidental sequence is more likely to happen if some barriers are not operational than if all barriers are effective. Knowledge on barrier efficiency is therefore essential for the localization of strength and weaknesses.

1.3. Theoretical background of organizational learning

Organizational learning can be defined as the collective phenomenon of skills acquisition and elaboration, which being more or less sustainable, modifies situations management and situations themselves [15]. Organizational learning relies on investigation processes taking place in the organizations when, for instance, some disparities between expected and effective results of actions are observed [16].

It implies therefore that some people learn for the whole organization. Koornneef and Hale define as learning agency these people who learn on behalf of the organization or ensure that the learning experience becomes embedded in the organization [17]. Nonaka and Takeuchi identified four steps within the transfer of knowledge from individuals to groups: socialization (from collective tacit knowledge to individual tacit knowledge), externalization (from individual tacit knowledge to individual explicit knowledge), combination (from individual explicit knowledge to collective explicit knowledge) and internalization (from collective explicit knowledge to collective tacit knowledge) [18].

Organizational learning also implies that the organization memorizes the collectively built knowledge. The main "knowledge tank" of the organization lies within the constitution of its operational routines [19]. Memory is therefore kept within work procedures as well as within training programs concerning new comers in the organization. Most of organizations also implement knowledge management tools like databases or expert systems that memorize organizational knowledge [20].

The issue of organizational learning is critical for risk-systems for at least five reasons [21–23]:

- Socio-technological evolutions of systems force the organizations to permanently update and adapt their knowledge and skills.
- Systems safety is built partly on theoretical data that everyday experiences allow to adapt and more accurately monitor.
- Production systems are sometimes made to last long after their designers have disappeared and the knowledge on their safety needs to be transmitted.
- Changes in the taskforce (new comers, outsourcing of activities, mobility, retirement, etc.) make it necessary that knowledge on safety is as transferable as possible.
- Organizations have moral and legal obligations to learn lessons from all incidents and accidents because public and authorities would not tolerate an accident knowing that it could have been avoided if lessons had been learnt from previous ones.

Organizational learning can be seen as the driving force of risk management activities (anticipation, vigilance and management of unexpected situations). The anticipation phase concerns safety process design, risk analysis, work procedures preparation, safety monitoring design, training, etc. During this phase, knowledge is created and people appropriate the system. The vigilance phase is composed of safety barrier maintenance, failures analysis and operational training. During this phase, knowledge is maintained in the organization and people learn to be reactive when confronted to unexpected events. The management of unexpected situations phase relates to crisis management. During this phase, knowledge is revised and people learn from the situated actions they do [8].

Risk management efficiency depends therefore on the way organizations learn and also on how learning is organized. Learning from experience implies, for instance, that each person involved in an incident or an accident take part in reviewing the information associated with the system failures [24]. Organizations must also encourage trust between these persons. Several factors imply trust. First of all, sanctions must be separated from reporting, i.e. people must not be afraid of taking part in incident or accident analysis even if they are involved in them. Trust also depends on the respect of people, i.e. people must not feel their knowledge is useless. Open communication is the third condition of trust, i.e. each person must be integrated into the communication process by the use of common language and shared tools [25].

2. Experience feedback from incidents and accidents based on bow-ties

We describe in this part how standard bow-ties were adapted and used in a Sanofi-Aventis plant for experience feedback. We first describe how bow-ties evolve, thanks to incidents and accidents analysis, then we describe the whole process of experience feedback organized with these bow-ties.

2.1. Bow-ties used to analyze incidents and accidents

The initial step of experience feedback by using bow-ties is their initial construction, thanks to risk analysis. In the plant we studied, safety experts (designers, instrumentalists, process safety engineers...) of the plant had already identified and analyzed seven critical events: loss of containment, contained mixture of explosive materials, deviation of process parameters, increase of pressure, non-desired mixture, mechanical aggression and documentation failure. They then constructed seven "standard" bow-ties corresponding to each scenario. They particularly made efforts in using generic vocabulary so that these bow-ties could be used in the different workplaces of the plant. Some of these bow-ties were even used in the legal document concerning safety in the plant. Fig. 1 represents one of these bow-ties (loss of containment illustrated for HCl).

Production managers then constructed their "local bow-ties" in relationship with safety experts. These local bow-ties were adapted to the risk and equipment of their workplace. These local bow-ties were drawn on A4 sheets of paper because they were to be simple enough to be used by non-experts. Some other data (emergency plans, experience feedback, etc.) were also added to complete the information needed to understand the local bow-ties. The local bow-tie shown in Fig. 2 corresponds to the translation of the global bow-tie on HCl release for a specific equipment in one of the workplaces of the plant. One can see that specific devices like valves or discs are named. Information on locations (e.g. height of the release) and on the concerned step of the process (e.g. chlorhydratation phase) is also added. The number of faults and events is also adapted to the situations. For instance, as no hose is used at this step of the process, the partial fault tree concerning the rupture of a hose was taken away.

The second step of the experience feedback process was related to incidents and accidents analysis. Each incident or accident was examined and displayed in the form of a bow-tie. This phase concerns both production staff and safety experts. It appeared to be facilitated because different persons shared a common representation of risky situations, thanks to local bow-ties.

This second step was closely linked with the third step of the experience feedback process. This one concerned safety barriers. The interest was to identify on the incident display the barriers that failed (and allowed the event to go on) and the barriers that worked (and stopped the event). This was done

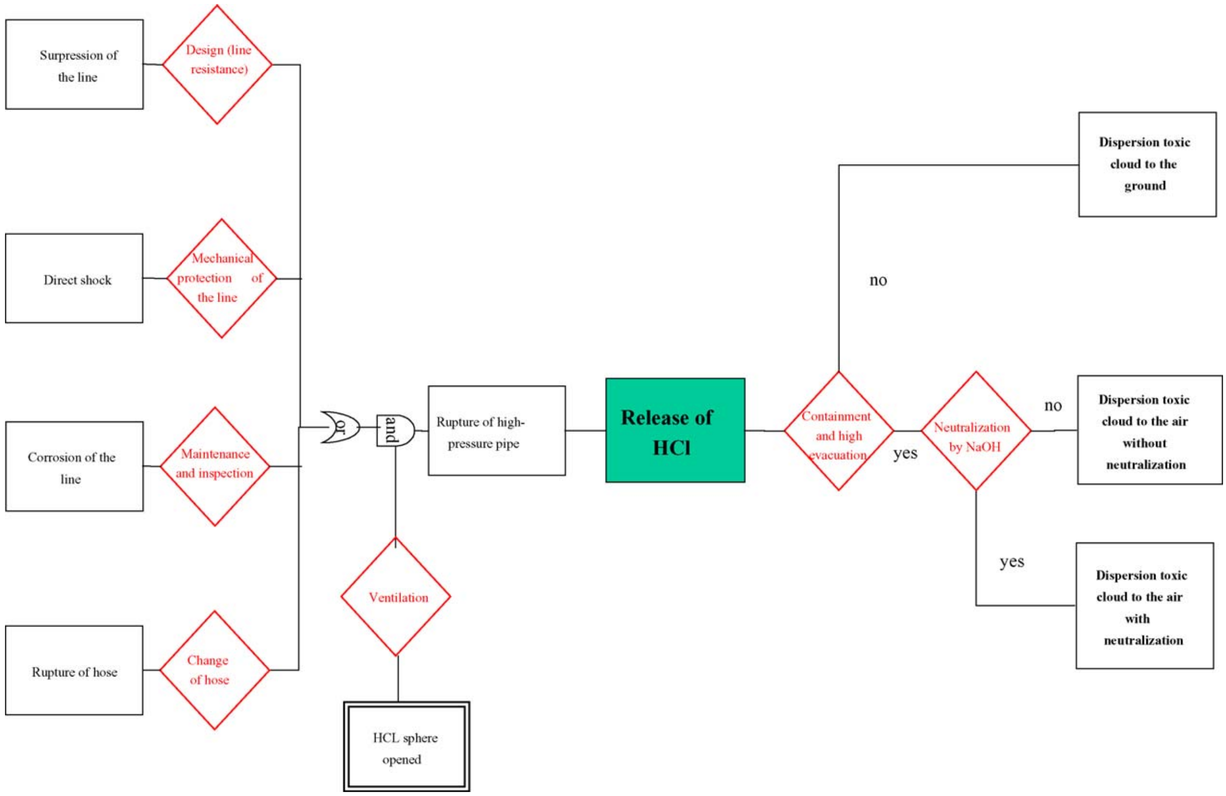

Fig. 1. Standard bow-tie for HCl release.

through the comparison of local bow-ties and the analyzed incident display.

The final step of the experience feedback process was the updating of local bow-ties. If unknown causes or consequences had occurred, they were added to the local bow-ties of the critical event concerned. The loop was then closed (cf. Fig. 3) to allow continuous improvement.

At the time of the study, about 80 events had been analysed, thanks to local bow-ties. Even if it is not the purpose of our paper, we can give an example of what was learnt, thanks to this use of local bow-ties. The most important thing concerned pipe-blocking during transfer of material. This had been identified as a cause of leakage but not as a critical event itself. It appeared however that pipe blocks were due to several factors that had not been clearly formalized before (configuration of pipes, phase of the production process, etc.). This therefore required an eighth specifically adapted bow-tie.

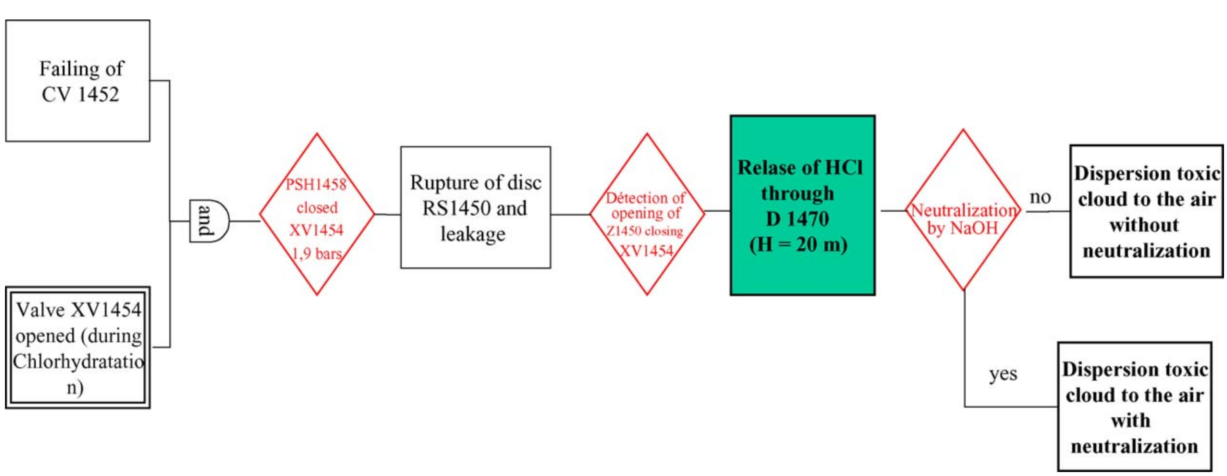

Fig. 2. Local bow-tie for HCl release.

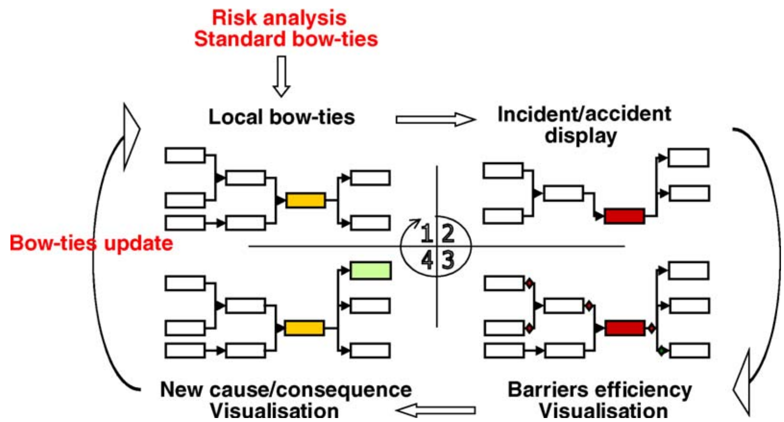

Fig. 3. Experience feedback loop based on bow-ties.

2.2. Organization of the experience feedback process

To better understand the experience feedback process using the bow-ties, we analyzed how the "local" level communicates with the "global" level. In our description, this "local" level will correspond to the staff of production workplaces that are not safety experts. These people deal with specific data and processes in contrast to the "global" level corresponding to the plant safety experts that need a global point of view of the safety of the site.

We observed that the bow-ties were used as a communication tool between these two levels. Local particularities (products used, equipment, safety barriers implemented, etc.) were, for instance, discussed when the local bow-ties were constructed. During the analysis of incidents or accidents, local people and safety experts also worked together when constructing the event display. The comparison between local bow-ties and standard bow-ties was in the same way an occasion of exchange, especially if bow-ties needed to be updated.

Communication between global and the local levels was made possible, thanks to the implementation of what we can call a "filter" that sorted the information to be shared. This "filter" between global and local levels was to ensure the relevance and the correctness of data going from standard to local bow-ties and vice versa. In practical terms, the people concerned by a bow-tie that needed to be constructed or updated composed this "filter". Safety experts were systematically involved in it, as well as production managers or operators depending on the case.

When events affected global safety, i.e. for instance, when a safety barrier seemed to dysfunction throughout different workplaces, safety experts and operators analyzed together the events in order to understand what happened. For this purpose, they confronted local and global bow-ties to represent and share their knowledge on them. Thanks to this, global and local bow-ties contribute to each other thanks to the action of the filter. We observed that this was contributing to the consolidation of knowledge of safety barriers and to the highlighting of new causes or consequences both in local and global bow-ties.

The whole feedback process organized around the "filter" (cf. Fig. 4), therefore, allows safety data to be updated at the local as well as at the global level of the plant. At the time we wrote this article, it was envisaged that a similar structure was to be set up between the different production plants of Sanofi-Aventis. The bow-tie representation had already been presented to production managers during a training course concerning safety. Safety experts had also worked on standardizing bow-ties between the plants.

3. Discussion: the contribution of the bow-tie representation to organizational learning

During the time of our study, we did not observed noted changes between the standard and the local bow-ties. This is certainly due to the fact that the standard bow-ties had been well constructed at the beginning. However, our results show that using the bow-ties within an experience feedback loop can contribute to organizational learning for safety. We can identify four dimensions of organizational learning that can benefit from the use of bow-ties.

First of all, bow-ties contribute to the formalization of knowledge on safety. This plays a role in the different phases of knowledge creation that Nonaka and Takeuchi identified [18]. First of all, knowledge is externalized and combined when the bow-ties are constructed. As each person, whether it be a safety expert or an operator, can be involved in this process, the explicit knowledge displayed on the bow-ties can be transferred from one to the other. The purpose of our study was not to study the internalization and the socialization phase of knowledge creation. We can, however, presume that a frequent use of the bow-ties as a communication tool between local and global levels as well as the integration into training courses on safety can play a role within these knowledge creation phases.

Knowledge is not only formalized by the using of bow-ties. Knowledge concerning several elements of the system safety is also created. The first step of knowledge creation occurs even before the use of the bow-ties within the expe-

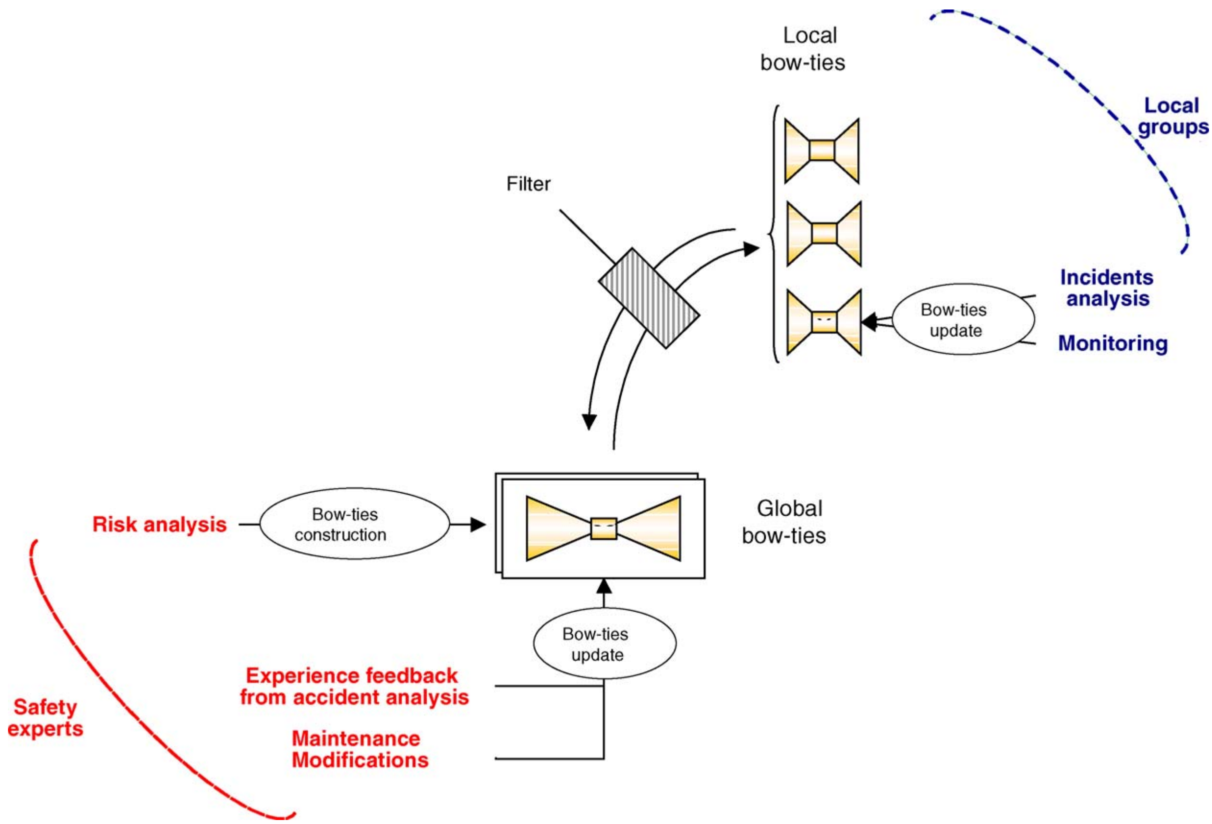

Fig. 4. Communication between safety experts and local groups.

rience feedback process. The initial risk analysis leading to standard bow-ties is the very first step of knowledge creation. As it is the result of the collecting and the perspective making on several types of data (incidents and accidents databases, expertise, technical standards, documentation or specialized literature, legislation), the standard bow-ties are themselves created knowledge. Knowledge is created as well during the translation from standard to local bow-ties. The adaptation to local specificities and the participation of local operators contributes to create of shared knowledge between all of them.

Knowledge is also created during the analysis of incidents or accidents with the bow-ties. The efficiency of barriers, for instance, is assessed by the comparison between these bow-ties and the consequences of real events shown on local bow-ties. As it is possible to locate in the bow-tie diagram where (on which barrier) the incident or the accident stopped (if it stopped), it is then possible to compare the observed and the potential consequences. The gap between the two shows the capacity of safety barriers to stop this event, i.e. if barriers existed, if they were active, which one failed, which one was able to stop the event, etc. The analysis of similar accidents can therefore create knowledge on the efficiency of barriers. The project of Sanofi-Aventis to generalize the bow-ties diagram between the different plants may also be a good opportunity to create knowledge. Used to compare different systems, they can help safety experts to harmonize their levels of safety and therefore learn from other experts. This should however be confirmed by further analysis.

Another important dimension of organizational learning to which bow-ties participate is organizational memory. The first step in constituting this memory is the construction itself of the standard bow-ties. Safety experts do initial risk analysis. Their knowledge at a given time is thus translated and stored into the standard bow-ties. Even if these bow-ties can be updated during the whole process of experience feedback, the former ones can be stored to keep the memory of safety barriers and known faults and events. This is certainly not sufficient to keep the whole memory of the system. The memory of the plant is also kept in work procedures, incidents and accidents analysis or engineering documents, for instance. But the bow-ties seem to have their part to play.

The fourth contribution of the bow-ties used within an experience feedback process is the constitution of a learning agency. The whole process actually organized around the bow-ties (construction, diffusion, adaptation and updating) is based on collaboration between all the people concerned by safety in the plant. Open communication is ensured by the fact that everybody uses the same representation. What we called the "filter" contributes to the fact that knowledge gained from incident and accident analysis becomes memorized in the organization. Depending on the context, the filter has sometimes been extended. Standard bow-ties have been, for instance, communicated to competent authorities and social partners. This collaboration contributed to the construction of a shared vision of risks among all these people. In these situations, the filter did learn and teach on behalf of the organization. The learning agency is therefore the combination of the filter that learned and the updated bow-tie that keeps memory of the knowledge.

4. Conclusions and perspectives

We have shown the interest of bow-ties as analysis tools for incidents and accidents as well as communication tools on safety issues. Maintained by a learning agency, they contribute to organizational learning by memorizing updated safety data. The implementation of this method of experience feedback can certainly be easily coupled with the implementation of the Aramis method. It might also contribute to preventing the “freezing” of knowledge on risks.

Bow-ties in fact can contribute to each phase of risk management as Wybo described them [8]. The bow-tie representation is a tool that was designed first for initial risk analysis. It participates thus to the anticipation phase of risk management. We think that it could also be used for everyday monitoring of the system (vigilance phase), especially for incident and accident analysis. Bow-ties can also play a part in the improvisation phase, on the condition that they represent updated situations. To paraphrase March, we can therefore say that the bow-tie representation contributes to developing within an organization common understanding of its experience and making its interpretation public, stable and shared, which is a contribution to the reliability of learning [26].

In the case we studied, the company had a long experience with the use of fault trees. This may explain the success of the implementation of the bow-ties in the plant we worked in. However, every company aiming to implement or revitalize its organizational learning processes on risks might benefit from the use of bow-ties.

A training course integrating the bow-tie representation is being set up and will be taught to management staff at the end of 2005. Its impacts on the appropriation of risks and on behavioral changes of trainees evaluated.

The results we have already obtained could contribute to the implementation of the Aramis method in industrial plants as it gives industrialists an insight of what they could get from it. Above all, this would contribute to reinforcing learning from experience and at the same time improve industrial safety practices.

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