Heuristics and ontologies as keys to enter complex organisational systems : virtual reality (VR) applications to improve industrial safety

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« Heuristics and ontologies as keys to enter complex organisational systems: Virtual Reality (VR) applications to improve industrial safety »

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Abstract :

A major issue in industrial safety is that different stakeholders, namely those involved in the generation, mitigation and monitoring of industrial risks (both occupational and of major accidents), develop different perceptions of what industrial safety is, or how it should be achieved. Because they differ, these representations generate likewise different analyses and assessments of industrial safety features and levels. When diverging, such risk perceptions can be detrimental to an optimal ownership, and hence successful implementation, of safety management systems in industrial systems (facilities, plants and organisations). It is therefore a challenge for risk managers, both within industrial facilities and from research and consultancy institutions, to adequately seize the nature of these representations, and how they materialise, both at individual (worker's, manager's) and collective (group's) level. In this respect, the involvement of these stakeholders is a major asset to understand the construction process of these representations. Ontologies of industrial activities and related risks appear as a key concept to reconstruct industrial safety in a participatory, user-based manner. Based on a the observation of real-life cases and related interview material, some of which conducted in the framework of the EU-funded VIRTHUALIS project, this communication presents a virtual reality (VR) application of the ontological approach to design interactive tools enhancing industrial safety.

Keywords : industrial safety, ontologies, virtual reality

Introduction

Risk and industrial safety are social constructs. While performing their daily professional tasks and duties, stakeholders within hazardous plants (namely workers, supervisors and managers) tend to develop autonomous intervention strategies. These have been developed individually and collectively, and are based on know-how and other cognitive resources. This set of resources that have been empirically developed can be described as a *heuristics* of production and action.

When considered from an industrial safety perspective, these stakeholders also appear to be involved in the generation, mitigation and monitoring of industrial risks – both occupational health issues and prevention of major accidents. Consequently, these stakeholders develop different perceptions of safety: what it is, an how it should be achieved. Because they differ, these representations generate likewise different analyses and assessments of industrial safety features and levels. When diverging, such risk perceptions can be detrimental to an optimal ownership, and hence successful implementation, of safety management systems in industrial systems (facilities, plants and organisations).

It is therefore a challenge for risk managers, both within industrial facilities and from research and consulting institutions, to adequately seize the nature of these representations, and how they materialise, both at individual (worker's, manager's) and collective (group's) level. In this respect, the involvement of these stakeholders is a major asset to understand the construction process of these representations. Capturing ontologies of risk therefore plays a major role in undertsanding different perceptions of risk existing in the workplace. This approach will be relied upon to "reconstruct safety", based on the original contributions from workers. The virtual reality application VIRTHUALIS is designed to contribute to that purpose.

VIRTHUALIS is an Integrated Project, in the 6 PCRD, priority 3 - New Production Processes and Devices - co-ordinated by the university Politecnico di Milano. The poject began in April 2005. The main feature of VIRTHUALIS proposal is to produce new knowledge and, as such, is answering to the undeniable need of transforming industry towards high-added value organisations, i.e., more knowledge-based ones.

VIRTHUALIS proposes the development of a new user-centred technology coupled with advanced safety methods and aspects that can be effectively applied in industrial applications handling hazardous materials. The proposal supports the life-cycle safety of industrial production systems through the aforementioned approach that will lead to a distinct minimisation of risk and therefore also of plant accidents. To support such ambitious goals and ensure their relevance and proper implementation, the project has a strong industrial participation in the Consortium. The influence from industry (objective-driven approach) is guaranteed in practice by its representatives in key positions. It is worth noting that all participating industries are subjected to Seveso II legislation. The VIRTHUALIS technology, will make it possible:

- to incorporate the most advanced HF concepts when performing the three safety actions, i.e., training, safety analyses (risk assessment and accident investigation), and safety management & audit;
- to move from static and paper-based safety analyses, in which the goodness of outcomes is strongly dependent on assessors' imagination and interpretation, toward dynamic virtual simulations.

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VIRTHUALIS technology will be made up of a set of four independent tools each built and shaped to dynamically perform the three safety actions:

- Risk Assessment & Accident Investigation Activities
- Training activity
- Safety management activity

This paper is organised as follows. The first section describes the objectives of the virtual reality application we aim to build. Section two present INERIS's data conceptual model called SIRI (System for Integration of Risk Indicators[2]), and a possible way of using it to build a virtual reality application. The paper ends with a description of lessons learned in user-based design of virtual applications for industrial safety.

I. A virtual reality application to tackle issues of representation co nstruction process

I.1 Problem to be solved

In the following section, we won't describe an existing application but our vision of a possible application to develop in Virthualis project. This description is necessary in order understand the possible use of the data conceptual model proposed in section tow.

The application we have in mind will help to tackle the complexity of a major problem in safety management. This problem is: to find the best possible ways to perform different objectives in the same time. These objectives include: production and productivity, health and safety duties, and environmental protection tasks. Teams, at plant/factory level, have to find the best possible strategies of performing their professional tasks/duties, while also taking into account that numerous risk factors likely to disturb the conditions to and means of their actions, depending on the context/situation.

The analytical step of "risk analysis" helps define accidental scenarios that workers must avoid. These scenarios have implications in terms of production, health, safety and environmental issues. The safety management activities define sets of "action scenarios" of doing a given work (or performing tasks) in order to avoid accidental scenarios. We propose to consider that management activities are related to (explicitly or not, deliberately or not,

[2] SIRI is one of the knowledge developed by INERIS in the European project called VITHUALIS: Virtual Reality and Human Factors Applications for improving Safety (42 partners, 14 millions euro).

realistically or not, with or without commitment) a sort of roadmap, rather than to en explicit, written strategy about the way of doing a work. Based on the sociological scheme called "individualism methodology", or of the "organisational sociology", this kind of strategy:

- is the result of the aggregations of individual behaviours (more or less negotiate),
- knows systemic dynamics (equilibrium, feed-back loops),
- is related to organisational informal rules.

Some psychological approaches to these issues propose criteria to analyse the strategies from a safety point of view. Athos follows the approach identified by the author René Amalberti3, based on the concept of cognitive compromise and on a subjective view of what risks are deemed acceptable, and what are not. It is not the purpose of the present document to go further into details, such as human sciences definitions. Rather, we would like to rise the specific sociological and psychological issues that are connected to safety management activities.

At this stage, the notion of good practices appears to be the best way of describing the issue at hand. Good practices indeed stand for an integrated roadmap and set of actions that are used by workers to carry out their daily professional duties/tasks. Despite the significant influence of explicit rules, such as regulations and procedures, this kind of "written directions for practice" appear less relied upon by workers in comparison to non-written rules. In other words, individual and collective strategies sustaining realisation processes rely on specific, cognitive compromises and subjective assessment of acceptable risks.

The management of good practices is not difficult because a high technical level is required for a specific action. Rather, it is difficult to develop procedures for managing good practices properly. This is difficult for both individual (worker-by-worker) and collective (teams of workers) activities. Purpose of this management task is to identify/design effective and efficient strategy(ies) with which workers are capable of adequately performing all barriers in the same time, taking into account the possible risk factors (degradation of the work context or reduction of resources). In that respect, the fundamental difficulty is that workers (and managers) have to perform an integration of numerous goals within one strategy of daily professional practice.

The Virthualis technology could be used to design and validate good practices and resources (both human and material ones) that are required to ensure the implementation of good

[3] Amalberti, R., 1996, La conduite des systèmes à risques, Paris: Presses Universitaires de France (PUF).

practices. Here, from a safety management point of view, one of the major difficulty is related to representation construction process (common ground elaboration), communication, needed to design and validate good practices, and resources (human and material) required. The direct consequence of a bad representation construction process is a bad commitment.

I.2 Virtual reality application

We have in mind a sort of "serious game" usable with a simple computer and an animator. This application don't specifically need data gloves, head mounted displays, haptic devices, 3D sensors, etc. The users (operators, managers, teams …) have a mission to do. They have to invest on safety solution without loosing too much time and money. The "serious game" could have four phases:

1. Users have a presentation of their mission. As it is in real life, they have documents: risk analysis, manpower planning, etc. Players can choose different positions in the team: operator (with specific task) or manager (in charge of a global control and decision making).
2. Users enter their workplace. They have to check the place. We can imagine a static scene or a dynamic one (other people are working, a catastrophic scenario is under prepare). Users have to decide: is it a safe place? does my team have adequate means to work in this context and to perform Quality, Safety and Environment objectives? If they decide that the answer is "no", they have to propose modifications. They can propose to change: objectives, means or elements of their work context. They can say that they want to stop at this phase of the game because there is to many safety problems … and solutions are to expensive (time and money).
3. In a third phase, the work begins … but the team faces a set of pre-accidental situations. Taking into account modifications and organisations chosen during the phase two, different accidental scenarios will take place.
4. Replay phases two and three to define best strategies and resources allocation in order to respect basic HSE rules in such situations.

Example of a possible scenario:

- During the phase two, the team working on substitution of a pipe used an explosimeter, but without checking it before. The explosimeter had fallen on floor and is now broken inside. They did not detected potential flammable dust (see Fig. 1).

- During the phase three (during their work), there is dust in suspension in air. Then, they make a hot spot, an ignition source. There is: dust explosion overpressures enclosure, an internal overpressure (Solid material), and a catastrophic rupture.

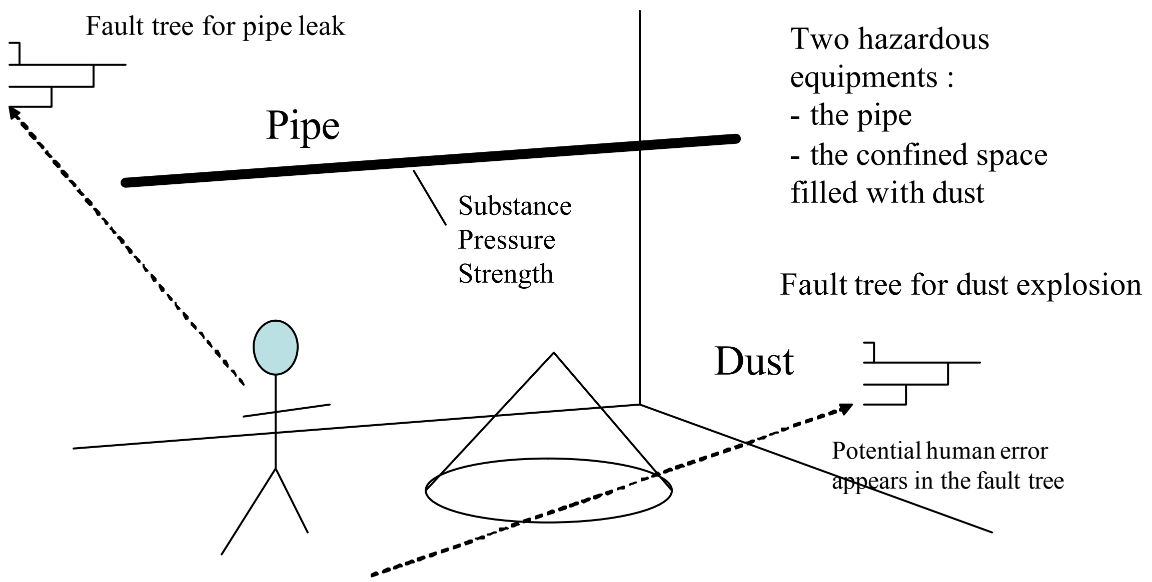


Fig. 1: Description of a possible scenario for a situation of threat to industrial safety.

The purpose is to work on:

- A better definition of the basics HSE rules to respect. Those rules can be explicit by:
    - What workers must not do (never!),
    - What workers can do under some specific conditions,
    - What workers have to respect absolutely during their daily job,
    - Control check- list of potential perturbations workers have to take into account.
- Necessary negotiations about strategic (or tactical) interventions and resources needed (technical, organisational and human).
- Set of examples illustrating complexes boundaries between what workers have to do and have not to do :
    - When and how ones has to stop the work because of safety difficulties, (and where are the "safe places")
    - When and how ones has to check work situations : be careful to co-activities, don't entirely trust procedures and documents, don't entirely trust work of others

- When and how ones has to check equipments and good use of equipments : be careful to the condition of use of sensors, refuse equipment lending …
- When and how ones manages planning and goals modifications during tasks: be careful of new orders from no technical managers or managers who don't follow modification procedures.
- How to manage psychological pressure, time pressure…
- How to manage conflict situation
- When and how ones has to communicate with others

II. Input from INERIS: a data conceptual model

It is clear that INERIS is not able to develop such virtual reality application by itself. The whole Virthualis consortium (Human Factor Experts, Virtual Reality Expert and End-users) is needed. What we want to present here is the specific data conceptual model proposed by INERIS to collect all necessary data needed for the application.

I.1 Problem to be solved

What are the models required by the application? At this stage of project development, the project team and authors do not have a definitive answer to that question. However, it is already clear that the application has to allow the visualisation of at least three different kind of critical safety elements:

Visualisation of objectives to be performed (as identified through risk analysis)

The objective here is to perform tasks in order to avoid production or HSE accidental scenarios. Basically, if one cannot visualise objectives to perform, one cannot find either the best possible ways to perform it in the same time. Objectives to perform are production and HSE ones to achieve; in other words: avoiding production or HSE accidents.

- A virtual model of the plant: the model is composed of various geometrical elements with physical properties attached to them. Somehow, this model constitutes the landscape in which human beings will operate and where accidents will take place.

- A model of the functioning (or process model) of the plant: this model specifies the internal behaviour of plant components. Somehow it is a process model. E.g.: "When button A is pressed the pump is turned on and the fluid passes into the pipe".
- A physical model that describes the phenomena that could give rise to accidental events. E.g.: "If the pressure raiser in the pipe is above 7 bar, then the pipe envelope fails, which causes leakage".
- An accidental sequence model that describes the causes of the accidental events: This model can be explicit or implicit depending on the quality of the process model and physical model. In the case of very complete models, the simulation of initial causes should lead to the final accident.
- A model of technical barriers. This model specifies the specific behaviour of technical barriers on accidental scenarios.
- A model of operating modes (human barriers): this is the sequence of operations performed in order to achieve a given production and/or HSE goal.

Visualisation of possible ambient and working conditions (variations and degradations)

- If one cannot visualise possible ambient or working conditions, one cannot see either the difficulties that need to be taken into account.
- A model of ambient conditions: temperature, humidity, illumination, time of day (or night), noise, etc. These are all factors that have an impact on the well-being of the operator (depend on the operator's perception of them), hence on performance efficiency.
- A model of working conditions: workplace design, team support, co-workers, working hours, dangerous space, narrow or elevated work space.

Visualisation of resources (variations and degradations)

Without visualising resources (human -people and teams- and technical resources -tools and materials-), it is not possible to work on possible ways to perform HSE objectives taking into account variations and degradations of possible working conditions.

- Human resources:
  - A geometrical model of human and movement model of human.
  - A cognitive model of human. This model describes how an operator acts in a given environment under given intentions or constraints, including a model of

psycho-physical, physiological or emotional possible states, taking into account level of competencies.

  - A behavioural model of a team : coordination and communication modes between operators : manpower planning, process of decision making, information channels, identity build-up, commitment, level of co-operation and reciprocities in relationship, confidence level between operators or between operators and the technological system.
  - An interaction model of human with the plant. This model describes, for each component, the type of interaction a human being can have with the component.
  - A human error model which specifies how an operator can make mistakes in a given situation. Such a model should describe the types of errors that can be made with a given occurrence law. It should also specify how these mistakes can be translated into the physical and process model of the plant.

- Technical resources:
  - A model of tools, interfaces or equipment characteristics that human can use.
  - A model of task instructions (procedures, written or oral prescriptions).

The breakthrough provided by the SIRI approach (see below for details) is to integrate data which are usually not. These data include:

- Accidental scenarios and barriers of Seveso plants
- Accidental scenarios and barriers of "substitution of pipes" activities
- Organizational difficulties (coordination, communication, cooperation, competence, tool and procedure)
- Actor's representations and strategies

II.2 Data conceptual model proposed by INERIS

INERIS propose an approach called SIRI (System for Integration of Risk Indicator) based on:

1. ARAMIS methodology[4] to structure accidental scenarios and barriers data of Seveso plants and of activities like substitution of pipes.

[4]/ ARAMIS is a European method whose development was inspired by LOPA and, which proposes more advanced tools in order to take into account organisation and human factors. ARAMIS, and therefore SIRI, boast the originality of suggesting an approach by what is called "barriers " which allow to achieve the integration of technical, organisation and human factors. Please visit http://aramis.jrc.it/index.html for details.

2. A processes approach to structure organizational difficulties
3. Fact Mirror methodology to tackle actor's representations and strategies.

ARAMIS' way of structuring accidental scenarios and barriers data

ARAMIS provides:

- Generic data: type of unit on a Seveso Plant, list of hazardous equipments, generic fault trees, generic event trees, list of safety barriers,
- A methodology to collect specific data.

All these elements can be used to produce virtual environments:

- Generic or specific components with hazardous properties and useful characteristics
- Some scenarios must be translated into the attributes of hazardous equipments
- An equipment will have the following attributes :
    - Parameters involved in the hazardous scenario (pressure, temperature, strength,...)
    - Laws describing the evolution of internal parameters due to external events
    - Hazardous scenarios describing the sequences of events leading to hazardous situation
    - Set of probabilities of external and internal events that are not resulting from the interaction of the user with the system

SIRI proposes tables of:

- Scenarios:
    - Undesirable Events, Detail Direct Causes, Direct Causes, Necessary and Sufficient Causes, Critical Events, Secondary Critical Events, Tertiary Critical Events, Dangerous phenomena, Major Events.
    - SIRI propose this structure for both major hazard and occupational accidents. Of course, this is often less detail for occupational accidents (scenarios are more simples).
- Barriers:
    - Safety Function
    - Detail Safety Function
    - Elements of barriers (technical or human)

- Set of performance indicators of a barrier: Independence, capability to perform the safety function (taking into account kinetics of accidental scenarios), level of confidence

SIRI crosses those tables in order to have links between major and occupational scenarios (when occupational scenarios create Undesirable Events), and barriers.
In this approach:

- Human Factors is identified as a cause in most of accidental scenarios (fifth level of the fault trees, mostly not exploited in the traditional risk analysis)
- Human Factors can intervene through direct Human Error (leaving a valve open, pressing the wrong button) or indirect (error in the design phase or maintenance phase)
- Some Human Errors can be supposed as preexisting in the system (attributing probabilities to some of them)
- Some Human Errors can be the result of a simulated behavior of virtual agents
- Some Human Errors can be the result of decisions by the user of the system.

Processes approach to structure organizational difficulties

We believe that the best way to model different stages of each action to perform in order to manage barrier's performances is the "Process approach" from ISO 9000. ISO is well known (Iso's purpose is to facilitate international trade by providing a single set of standards that people everywhere would recognise and respect … ISO 9000:2000 standards apply to all kinds of organizations in all kinds of areas).

The ISO 9000:2000 standards identify three types of processes to ensure the effectiveness and efficiency of "realization processes":

- Processes for management of an organization ("Management processes"). These include processes relating to strategic planning, establishing policies, setting objectives, providing communication, ensuring availability of resources needed and management reviews.
- Processes for managing resources ("Resources processes"). These include all those processes for the provision of the resources that are needed for the processes for managing an

organization, for realization, and for measurement. Examples of resources include: Human resources, Materials, Financial resources, Information.

- "Measurement, analysis and improvement processes". These include those processes needed to measure and gather data for performance analysis and improvement of effectiveness and efficiency. They include measuring, monitoring and auditing processes, corrective and preventive actions and are an integral part of the management, resource management and realization processes.

This approach can be follow to define set of activities in charge of barriers. SIRI combines generic ISO processes and ARAMIS network of delivery systems. For instance, the ARAMIS delivery system of "Maintenance repair and modification" (see Fig. 2 below) is link with resources processes and "measurement analysis and improvement" processes.

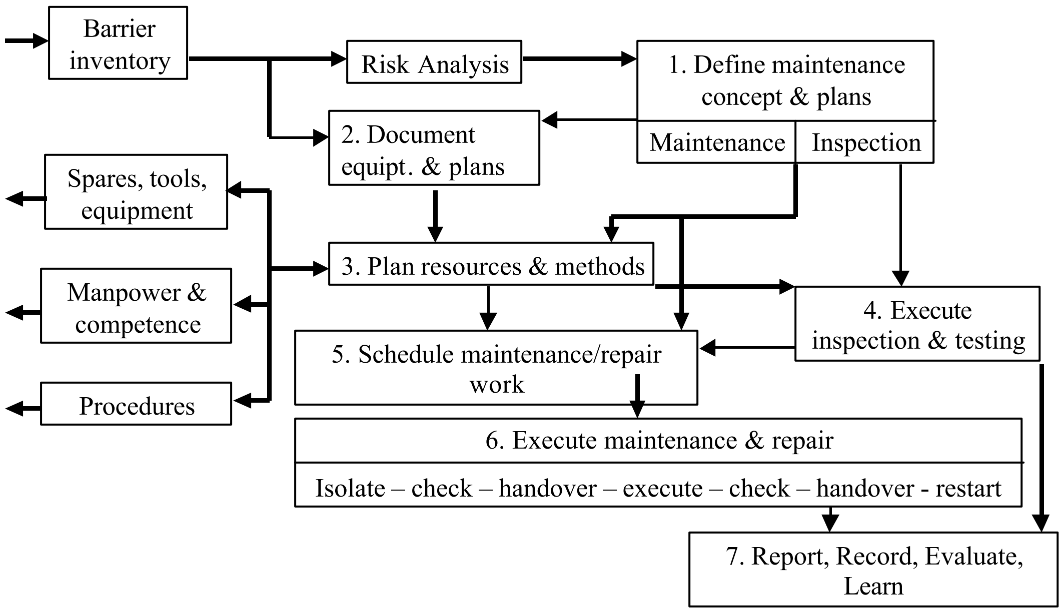


Fig. 2: ARAMIS view of the "Maintenance repair and modification" delivery system

For each process, SIRI links the following elements, data or information items[5]:

- Lists of actors involved in HSE issues;
- Organizational factors (or delivery systems): job and task instructions (procedures required, written or oral communications, work methods, plant policies, …), motivation and attitudes, knowledge required, emotional state, working conditions, adequacy of

[5]/ These links have been built in ATHOS research program which is finance by PICARDIE's region. ATHOS is a method based on ARAMIS approach. ATHOS proposed improvements on Human and Organizational Factors.

man-machine interface, number of simultaneous goals, available time to carry out a task, time of day, crew collaboration quality, psychological stressors (duration of stress, task speed, conflicts of motives about jobs, inconsistent cueing etc.), physiological stressors (fatigue, pain or discomfort, movement constriction, lack of physical exercise etc.).

Data of actor's representations and strategies

SIRI links accidental scenarios, barriers, processes and actors with data from Fact-Mirror[6] (Fears Attractions Temptation in Mirror) methodology which allow tackling some critical actor's representations and strategies. Representations and strategies we want to work on with the virtual reality application.

Fact-Mirror is based on an interpretation of the strategic dilemma (prisoner's dilemma) in terms of Fears Attractions and Temptation. The main idea is that revenues of interactions are difficult to calculate in mathematical terms in everyday life, but the feelings of actors submitted to such a dilemma can be easily anticipated, though they will of course be experienced in a specific way of each individual:

- The Fear of being betrayed and of suffering the consequences corresponds to the difference between the loss and the sucker's pay-off;
- The Attraction of achieving mutual co-operation because they want to succeed together corresponds to the difference between the rewards and the loss;
- The Temptation to betray the other, to benefit from the betrayal bonus corresponds to the difference between the revenues from betrayal and the reward from co-operation.

In the Fact-Mirror perspective, actor's strategies are based on estimations of the trust one can place in one's actor, often made unconsciously and resulting from the history of interactions. These estimates are going to affect the choices made by actors, and the subsequent moves made by each by increasing or decreasing the degree of trust in one's actors. Fact-Mirror method involves evaluating these degrees of trust by the way in which the revenues of the other are taken into account during the development of the strategies of each actor.

[6]/ This methodology has been develop by Gilles Le Cardinal, Jean-François Guyonnet and Bruno Pouzoulic, and adapt to Quality Safety and Environment issues with INERIS in the ATHOS research program (finance by PICARDIE' region).

Fear, Attraction and Temptation are not only an indicator of the quality of relationships but also a way of discovering actor's representations and strategy in a systemic perspective. Also, the work on the sentiments of the stakeholders of a complex problem is the first step in creating a climate of trust. Fact-Mirror proposes to put these sentiments into words. Through their answers to three questions: "what are oner fears, oner attractions, and oner temptations in the interaction under study" the actors become more conscious of the stakes involved in each encounter. Increasing the interpersonal trust between participants will lower the fears and the temptations and make more realistic the attractive aspects of the situation. Also by actually lowering the fears and temptations and increasing the attraction, trust grows.

Practically speaking, the method proposes five steps:

1. Definition of project, mapping of actors involved. In the perspective of our virtual reality application, the project is linked to processes (barriers) that actors have to manage. This project allows identifying all the important interactions to work on in order to uncover actor's representations and strategies.
2. Secondly, for these important interactions the three feelings of fears, attractions, temptations are expressed in a brainstorming workshop or in individual interviews. Dangers or a sterile discussion or insufficient justifications are avoided. What is said is legitimate which in no way stops one of the participants from making a statement, which opposes that of the rest of the group. All the points of view are taking into account. A logic of AND is substituted for a logic of OR.
3. Thirdly, each participant is invited to make an evaluation by attributing a mark, anonymously, personally and therefore subjectively, to each proposition, according to his/her consideration of its degree of importance for the best resolution of the problem. Next, the marks of the participants are obtained for each statement taking the average of the marks obtained for each statement. This huge quantity of qualitative and quantitative information (between 200 and 1000 statements according to the problem and the time spent) collected from the participants in reply to only three questions, should next be reviewed and structured before being used by the search for solutions.
4. After stating the FAcTs, their notations, and obtaining the general classification, in a fourth phase, the group classifies the statements by affinity into 5-10 "unavoidable themes". Between 10 and different registers are opened, called the unavoidable themes of the problem.

5. The recommendations are built in a creativity workshop. The animator asks the group to consider: 1/how to suppress or reduce the fear in question, reducing the danger which it causes, 2/how to realistically obtain what was expressed as a potential attraction, 3/how to limit the temptation or make more difficult and less advantageous a betrayal (i.e., giving in to the temptation). In this way, each recommendation has a precise origin.

Following this methodology, INERIS and UTC have worked on subcontractor interventions in a Seveso plant. About 800 statements have been defined uncovering actor's representations and potential strategies of generic difficulties meet by actors (maintenance, production team, HSE team, supervisors, subcontractor teams, managers from Seveso plant and from subcontractor companies) to perform safety barriers and accidental scenarios (major and occupational hazard) they have to take into account.

Those data have been linked with eleven important processes of a subcontractor intervention: 1/Specifications elaboration, 2/Selection of subcontractor companies and business negotiations, 3/Program elaboration, 4/Visit and first preparation of the work to do, 5/Risk assessment (different specific document and permit), 6/Work preparation (by production people of the Seveso plant, 7/Control of entrance on the site, 8/Realization of the intervention, 9/Control, 10/Modification management, 11/Receipt of the work. The three feelings give much information about difficulties, representation and strategies meet by actors. These include for instance:

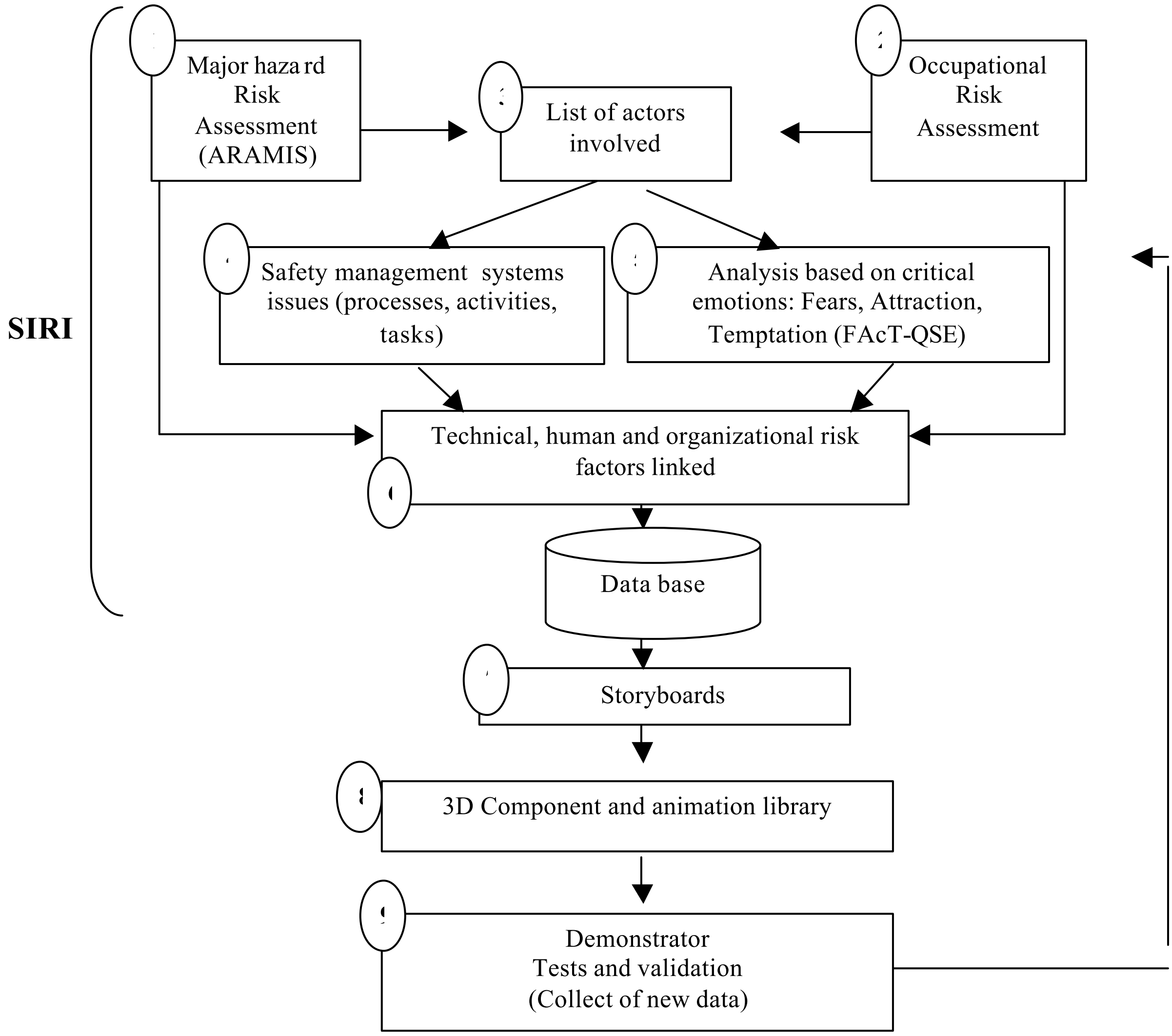
- Productive people don't define their needs with sufficient details, so maintenance is not able to define good specifications… subcontractors are not able to well prepare their work,… and production people ask them, during the realization phase, to perform (quickly) a new task without risk assessment.
- There is not enough availability of production team, so supervisors and subcontractors are really tempted to begin their work without permission … without confirmation that the wrkplace have been well prepared … without knowledge of specific risk in this workplace …
- Teams have a fear of new regulations… but not of some real risk as ATEX (dust explosion or other non intuitive dangerous phenomena).
- Maintenance and production team considered that safety team have not a realistic representation of their job and impose rules to them impossible to follow… that they don't follow many times…

Conclusion

The data conceptual model of SIRI propose to link different kind of data that a good safety management system has to manage. SIRI is capable to restore these data in order to prepare virtual scene and virtual animation needed to work on representation construction process. This is the breakthrough proposed by INERIS for a specific virtual reality application aiming at a work on representation construction process:

- A better definition of the basics HSE rules to respect. Those rules can be explicit by:
  - What workers must not do (never!),
  - What workers can do under some specific conditions,
  - What workers have to respect absolutely during their daily job,
  - Control check-list of potential perturbations workers have to take into account.
- Necessary negotiations about strategic (or tactical) interventions and resources needed (technical, organisational and human).
- Set of examples illustrating complexes boundaries between what workers have to do and have not to do.

A conceptual description of the SIRI model is provided below (Fig. 3).



the figure 3 above shows the input proposed by SIRI. But it shows also that it is not enough to have a demonstrator.

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