V3S : a training and decision making tool for modelling safety interventions on SEVESO sites

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V3S: A Training and Decision Making Tool to Model Safety Interventions on SEVESO Sites

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Abstract: V3S (Virtual Reality for Safe Seveso Substractors) is an ANR/RNTL project (French national agency for research). In this project, we aim to design a tool allowing to scenarise hazardous working situations on SEVESO sites for risk prevention, training and decision making. The tool interprets a high level task and a related risk model. It is meant for a manager to help him/her to make decisions. The manager plays the scenario of an intervention and manages a team of virtual operators (associated with autonomous agents) in the VERP (Virtual Environment for Risk Prevention) submitted to constraints. Depending on his/her decisions, the incurred risks are displayed in the virtual environment. Our architecture relies on a multi-agents platform (OMAS).

In this paper we present some of the features of the tool through different scenarios. We present the organisational rules of our system, how it self-adapts to the technical competencies and the characteristics of the operators (human factors). We also present the working environment hosting our agents.

Key-words: virtual reality, safety intervention, risk management, multi-agents system, interactive physical simulation

1. Introduction

The new possibilities offered by virtual reality in terms of scenarisation and the emergence of knowledge engineering tools for risk analysis give the opportunity of developing new tools to improve the training and decision making for risk prevention. Many industrial applications using virtual reality for risk management will appear in the near future. However, dedicated applications can only represent a partial solution. Generic tools, closer to the reality have to be considered. In the V3S project (Virtual Reality for Safe SEVESO Substractors) supported by ANR, we aim at developing such a tool for external maintenance companies that intervene on SEVESO sites. This tool has to allow to scenarise hazardous working situations on SEVESO sites with avatars and autonomous virtual characters, using virtual reality and artificial intelligence.

The tool is meant for a manager to help him/her to make decisions. The manager and his/her team have to appear in the VERP (Virtual Environment for Risk Prevention) and have to be submitted to its constraints.

Our hypothesis is that the effectiveness of virtual reality in terms of training and decision making for safety management increase when operators and managers see the impact of their decisions on the technical, organisational and human system they have in charge. The importance of virtual reality is undoubtedly a priority in the construction of a system dedicated to the simulation of safety interventions [1] [2]. The trainee will be able to build an adequate mental representation of the process and to learn from acting and interacting [3]. Furthermore, the challenge of our technology is to allow building customized simulations (usual procedures, progressive degradation of the working situations, etc.), adapted to the needs of our industrial partners. Indeed, taking into account the concerted requirements of safety is a challenge for the industrialists throughout the chain of decision that marks out the relations between the hazardous sites and the subtractors companies.

The tool has three main functions: (i) training; (ii) scenarisation; and (iii) decision making.

- Training tool

The manager comes to different possible choices like to train for activity preparation or to train in constrained situation. The constraints could have two origins: (i) the environment: difficult geographic morphology, cold, windy; and (ii) the physical or mental characteristics of the virtual operators (VO): tiredness, accumulated stress, hurry, hunger, alcohol.... As a training tool for preventing risk, the analysis and control of the risks on SEVESO sites have to be considered. Using virtual reality allows us to offer the users (operators and managers) the possibilities to become familiar with the site while displaying the plant under operation and finally to learn how to detect the defaults while playing the scenario of an intervention. The trainees will be able to supervise and verify essential check-points. Depending on different parameters, the proposed pedagogical scenarios have to present the inherent risk in this type of sites. The parameters are the manager's decisions, the environment evolution and the virtual operators' cognitive characteristics. Indeed, the virtual characters can simulate deviant behaviours in constraint situation, risky/hazardous operative modes or reach partial goals fixed by the procedure in an intelligent way. Learning by action will be possible if the trainees can efficiently and explicitly identify the technical, organisational and individual factors simulated by the VO.

➢ Scenarisation platform

The manager has to be able to rebuild accidental cases and replay the situation to understand the problems encountered by the operators, to conduct post-accidental risk analysis or to do critical event analysis. By immerging the final operators, the teams, the safety analysts and the directors in the virtual environments (VE) especially modelled for the training, it will be almost possible "to live" the critical situations, thus amplifying the operators experience and enabling them to suitably exploit the concepts of Human Factors and the good practices of Organization.

➢ Help in decision making tool

V3S has to offer the possibility to model the working environment and the selected operative mode. The virtual reality interface will be connected to a blackboard presenting the advantages and the disadvantages of the simulated solutions. With V3S, risk analysis before or after accidents (HAZOP, FMEA, tree of causes, tree of events, preliminary risk analysis, tasks analysis, etc.) could be done closer to the field realities, by integrating problems related to the Human and Organisational factors. The VERP resulting from V3S will improve the communication and coordination between the different actors (users and sub-contractors companies) and will therefore support the setting up and the piloting of an enterprise strategy well adapted to the context of the interventions.

In order to support the previous three points, we propose a generic tool. It will endow the environment with autonomous decisional capacities. We don't aim at neither reproduce perfect cognitive mechanisms nor describe the operator's cognition but we wish to simulate the behaviours which could occur. We will simulate the operative mode, the evolution of the operators, and the changes in the environment. The operators should adapt to the environment in an autonomous way. To give them the necessary cognitive capacities we propose an approach based on the concept of agents.

In a previous related work supported by ANVAR and VIRTHUALIS[1], UTC, ECI and INERIS have focused their works to demonstrate the feasibility of such a tool. A first demonstrator has allowed to scenarise two virtual operators and a real manager who have to intervene on SEVESO site. A multi-agents architecture (MASVERP) has been designed to manage the decisional process of the virtual agents, giving them autonomous capacities and organisational behaviours [4]. The previous architecture permits to show the feasibility of such a system by developing some of the necessary functionalities (planner, agent model and task model). MASVERP endow the virtual characters with autonomous decisional skills. The remaining work is to enrich, complete the model and to combine it with physicals and risks models. After this step, supported by ANR/RNTL, the V3S project has started in 2006 and will continue until 2009. CEA-LIST, SEEMAGE and industrials of the petrochemical area and dangerous products transport area have joined the project. In this larger project, the roles of the partners are

- ◊ UTC for the autonomous decisional capacities of the virtual agents,
- ◊ CEA-LIST for the simulation of physical phenomena, the behaviour of virtual manikins and the deformable objects,
- ◊ ECI for the human activity analysis and the ergonomic aspects,
- ◊ INERIS for the safety and risks management,
- ◊ SEEMAGE for the software integration,
- ◊ Petrochemical and dangerous products transport industrials for industrial needs.

In this article we present the functionalities of the tool through different examples and scenarios. We present the architecture of our system, the organisational rules, how it self-adapts to the technical specificities and the characteristics of the operators (Human Factors). We also present an example of a related previous work from the preliminary step.

2. State of the Art

2.1. Virtual Reality and Risk Training

Applications dedicated to risk prevention using

[1] VIRTHUALIS : Integrated Project, in the 6th PCRD (R&D Research Program)

virtual reality are just emerging and for the majority are still at the stage of laboratory applications. The NIOSH[2] and FIOH[3] first experiences published in 97 were related to handling and high working [5][6]. More recently, VTT[4] worked on a prevention measure application on industrial equipment [7]. In the domain of ergonomics, different researches study the sensorimotor and cognitive human behaviour and the analysis of the working situations and tool design [8][9]. Let us mention finally the domain of professional training where many studies and/or applications cases are done about safety [10] [11][12]. These different examples highlight the existence of an emergent need for VERP for the professionals. In this context, INRS started a multidisciplinary project in 2002, called EVICS[5], in order to evaluate the contribution of virtual reality in the domain of training addressing professional risks [13] and the conception of safe system [14]. In term of applications for safety we can also quote SécuRéVi (Security and Virtual Reality) developed by ENIB [12]. The project helps training firemen to the operational management and command.
VIRTHUALIS is an Integrated Project, in the 6th PCRD (R&D Research Program). The main feature of the VIRTHUALIS proposal is to produce new knowledge and, as such, it is responding 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 effectively be applied in industrial applications handling hazardous materials. The VIRTHUALIS technology will make it possible: Some partners of the V3S project are participating to the VIRTHUALIS project (INERIS, ECI) and some links exists on safety and human factors aspects.

2.2. Making decision and humans factors application

This research orientation relates to the technical or methodological tools of decision-making in the preparation and the management of sub-contractors interventions in the field of high-risk industry, highlighting the taking into account of the human factors.
The expression *"Human Factors"* is an umbrella term for several areas of research that include human performance, technology, design, and human-computer interaction. The approach focuses on how people interact with products, tools, procedures, and any processes likely to be encountered in the modern world. It regroups all the individual and socio-technical factors belonging to the working process. Human Factors practitioners can come from a variety of backgrounds; though predominantly they are Psychologists (Cognitive, Perceptual, and Experimental) and Engineers. However, Designers (Industrial, Interaction, and Graphic), Anthropologists, Technical communication Scholars and Computer Scientists also contribute. It is interesting to combine all approaches proposed by the researchers since they are complementary on the theoretical and methodological levels [15].
Among the various approaches for safety, one can distinguish between two main groups. On the one hand, the reactive approaches taking place after a critical event in term of health, safety and environment (industrial disease, incident, accident, major accident); on the other hand, the pro-active approaches to anticipate the occurrence of potentially critical events. The connection between various approaches is today a major stake of the research in order to find ways to improve the prevention and the reliability of the working system, and of the environmental risks.

2.3. Behaviour modelling tools

- STEVE

STEVE is a reference in the domain of behaviour modelling tools [16][17]. It is an autonomous, animated agent that lives in the virtual world with students. Its objective is to help students learn to perform physical procedural tasks. It can demonstrate tasks explaining his actions, as well as monitor students performing tasks, giving help when they need it. He has a cognitive mono-agent architecture based on SOAR [18] which allows him to know the state of the environment in real time, to decide what actions to undertake and how to reach his goal. In the MRE project [19] STEVE architecture is used to build an application for peacekeeping, it allows virtual characters to cohabit with humans.

- IRISA

IRISA has developed a large number of tools for behavioural modelling like HPTS++ or SLURGH [20][21]. HPTS++ is a behaviour modelling language for autonomous agents. The agents are organised in a hierarchy of automata. SLURGH is a scenario modelling language. It allows managing the scenario data and also the dialogue between the characters (actors). It creates a determinist scenario in which the actors have to share the resources using HPTS.

- GRIC-GRAAL

Developing a tool for training firemen aims at keeping them out of danger. To do so, the authors

[2] NIOSH – National Institute for Occupational Safety and Health (USA).
3 FIOH – Finnish Institute of Occupational Health (Finland).
4 VTT : Technical Research Centre of Finland
5 Virtual Environment for Safety System Conception

designed a virtual environment in which virtual firemen interact, driven by a human operator. The architecture of the system is based on a multi-agents system composed of emotional and reactive agents [22]. The agents have a goal to achieve; they use a Prolog planner to determine their actions. The plan is included in a file the agents can access.

- MASCARET (ENIB)

The physical environment represents a plant where the exercise takes place and also includes physical phenomena that can take place in the plant (fire, smoke, water spreading...). The trainees play the role of the different group managers who intervene during an incident and the trainer participates to the simulation as a troublemaker. He can create dysfunctions, help the trainees and, as a player, play a role in the team. The MASCARET model is proposed in order to organize the interactions between agents and to give them reactive, cognitive and social abilities to simulate the physical and social environment [12].

2.4 Multi-Agents System Approach

Proposed in the 80's, multi-agents systems now appear frequently in research activities. A multi-agents system (MAS) is composed of a number of agents that are interacting, cooperating and belonging to an organisation. We distinguish two kinds of agents: reactive and cognitive. Reactive agents only react to a stimulus (intern and extern) and do not use an internal symbolic representation. Cognitive agents are able to build their own behaviour and have a full representation of the environment. But this distinction tends to disappear in hybrid agents, a mix of both species.

Multi-agents systems are efficient to build systems where the notions of cooperation, organisation and autonomy are crucial. GRIC/GRAAL and MASCARET experiment this approach using emotional, reactive and rational agents.

2.5 The Positioning of Our Work

Contrary to the existing work, our approach is different. Indeed, proposed approaches relies generally on an architecture based on informatics foundation (automates, Petri network, expert system). Some works propose to build systems while taking into account cognitive behaviour model [23] [24] for virtual human animation for example [21].

In V3S, our foundation relies on cognitive models in the domain of safety and human behaviour in risky situations [27][28]. From these models, we propose new mechanisms to represent human decisional process and human errors finally simulate in a virtual environment. One of our added values is to propose tools integrating artificial intelligence to (i) analyse the human process and (ii) generate errors.

3. Technical and Scientific Objectives

3.1. General Objective

The project aims at exploring and demonstrating the impact on the operators training of a virtual reality tool including Human Factors in planning and in decision-making, in the context of high risk industry.

The originality of our project dwells in the coupling of knowledge engineering models with virtual environment for modelling safety interventions on a SEVESO plant (*Figure 1*). Knowledge engineering allows managing the knowledge in the different scenarios and provides with organisational and human generic databases.

The development of a generic tool in V3S is intended to integrate this knowledge in a risk calculator based on a computer model and to simulate these risks at a decisional level in a virtual environment. Another objective, at the physical level, is to make the scenarios as realistic as possible by animating virtual characters and giving physical behaviours to the manipulated virtual objects. This coupling will give the opportunity to integrate new experience feedbacks and new plants in a realistic simulation automatically. The tool will be used by several industrials and SMEs of the petrochemical area and dangerous products transport area.

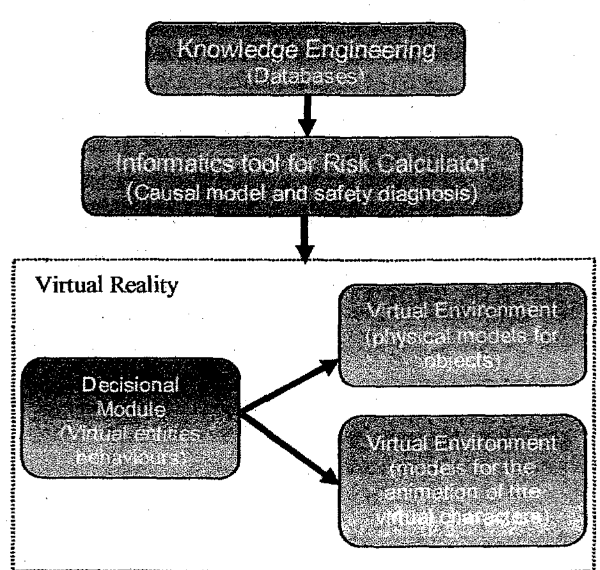

Figure 1 Coupling Knowledge Engineering and Virtual Reality

3.2. Our Architecture

To achieve our goals, several components have to be considered and developed (*Figure 2*).

◊ A framework is necessary to model and display the scene and the elements needed by the scenarios like equipments, tools and characters. The virtual scene will be built from CAD model. The complete simulation will be displayed in real-time in the VERP, to increase the realism for the user. It will be possible to navigate in the scene, for example by moving around an element (SEEMAGE).

◊ A physical layer to simulate the physical phenomenon implicated (objects and virtual characters) in the virtual environment. The module has to offer a broad range of elementary behaviours (CEA-LIST).

◊ A scenario catalogue grouping the risked-situations to process; such scenarios include for example a description of the working environment and the supervised chemical process, a description of the roles, or the task to achieve and the procedure to follow in a face to face operating mode, and eventually in a degraded mode or during particular critical phases (start, end, etc.) (UTC).

◊ A behavioural module according to the environment of the virtual characters and physical objects. The module aims at simulating physical phenomena such as smoke or dangerous liquid products propagation, virtual characters grasping tools, connecting a flexible, etc. (CEA-LIST).

◊ A decisional and diagnosis layer dealing with safety aspects. The decisional module has to give the virtual characters autonomous decisional processes. We intend to propose a generic model which would enable to easily direct, in a virtual environment, the behaviours of the operators intervening on a high-risk industrial site and the variations on the physical environment. The diagnosis module has to display the pedagogical feedbacks. This module has to identify the trainee behaviours, and to associate the causes and the appropriate feedbacks (UTC).

◊ An interface module linking the decisional and the physical layer (CEA-LIST, UTC).

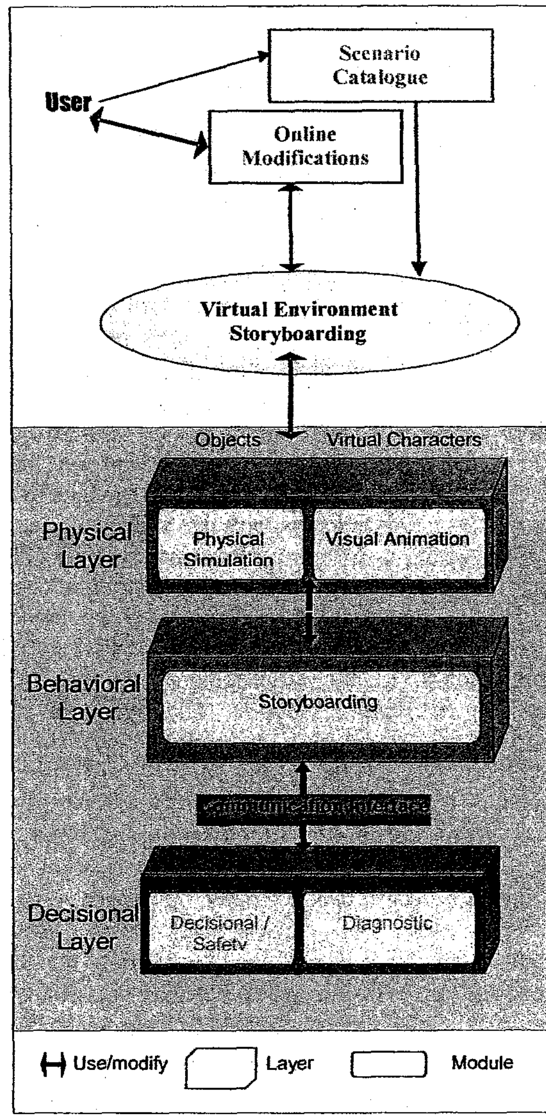

Figure 2 V3S Architecture

3.2.1. Decisional Layer

This layer relies on a multi-agents system with the following entries:

◊ A standard model of the activity. The model is based on a model describing the cognitive activity elaborated in the APLG project (RIAM project, [25], [26]). This model results from ergonomic, cognitive and artificial intelligence work (ECI). Some partners (ECI, UTC) of V3S are participating to PERF-RV2[6] and some connexions exist on these aspects and about its uses for virtual human scenarisation..

[6] PlatEfoRme Française de Réalité Virtuelle, french Virtual Reality Platform

◊ A risk model. The model will take into account all the risk factors defined with the INERIS databases which will permit to generate data link to the technical, organisational and human factors.

The main work of UTC is to rely upon the capacity of the agents to take their own decisions in an autonomous way. They should be able to:

◊ Generate a plan and assume different tasks

◊ Adapt and react according to the changes in the environment

◊ Move in a realistic way

We assume that a Multi-Agents System (MAS) is a solution to reach these three points in terms of organisation, cooperation and planning [4]. We consider three types of entities in the environment: reactive, cognitive and human. The reactive entities correspond to the objects in the environment, the cognitive entities are our workers, and the human is the manager who interacts with the VERP.

The objects have different behaviours but they only have to react to a specific action, a stimulus. For example: if the scaffolding is knocked down, then it should fall. They do not need to have a full representation of the environment and therefore they are considered reactive. The operators are more complex as we can see on *Figure 3* that shows the architecture of our system. We should consider their physical and mental characteristics according to the COCOM model of Hollnagel [27] [28] . Characteristics could be permanent (pm) or progressive (pg): safety (pm), prudence (pm), tiredness (pg) or stress (pg), etc. These characteristics are placed in the memory of the agent and are used to determinate in real time the behaviour (control mode) adopted by the agent [29] [30]. Such characteristics are taken into account to construct a cognitive activity model.

Here is the originality of our project; actually, depending on their personal characteristics they will have different ways to do the same task without or with risk.) The way is determinate by their decisional motor (planner) according to several parameters. The planner will take into account the task model, the risk model to provide a plan to the operators. It will be use also in the diagnosis module (*Figure 4*).

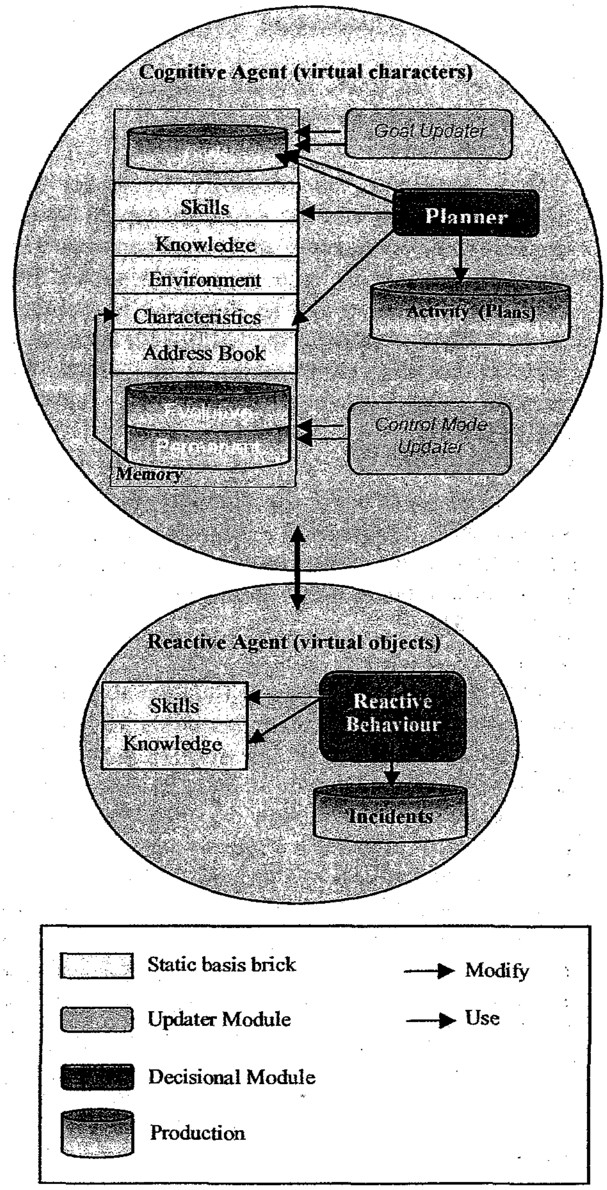

Figure 3 Agent Architecture

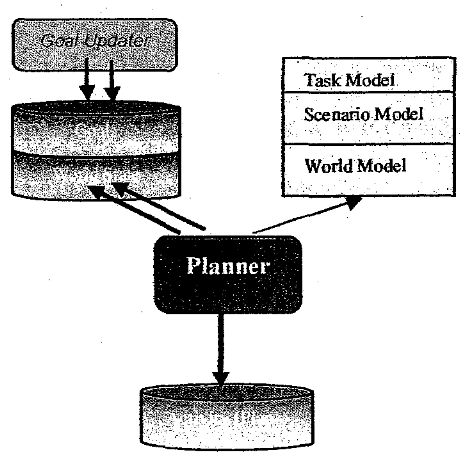

Figure 4 Planner Working

3.2.2. Behavioural and Physical Layers

In the scope of the V3S project, CEA-LIST partner aims at developing interactive simulation components. These modules will help to simulate in a simplified way some of the physics involved in the scenario:

- The motions of the objects in the scene
- The manipulation of pipes
- The propagation of fluids (smokes, dangerous liquid products
- The behaviour of virtual manikins (avatars of the real operators involved in the tasks) when physically interacting with the scene along the scenario

Some interactive simulation components are developed in PERF-RV2[6] and SYSTEM@TIC[7] project and will be integrated in this module.

Simplified propagation of fluids will be developed according to international recent work [31][32][33][34][35][36][37][38][39][40].

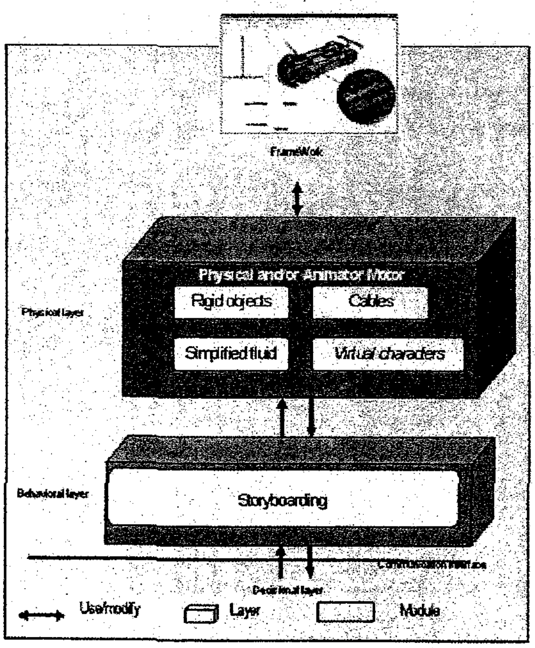

Figure 5 Behavioural and Physical Layers Architecture

4. Organisational Rules and Roles

In this project, we want to describe and simulate the cognitive mechanisms of human operators. We will therefore implement the physical behaviours realistically and in particular the cognitive decision. The operators represented by the agents evolve in an organisation, cooperate and aim at reaching a common goal. They are directed by a manager and therefore submitted to his orders. We describe the structural organisation as follows: in the organisation, an agent can play one or more *roles*, to determine which agents typically need to *interact* with others to exchange knowledge and coordinate their activities. These interactions occur according to patterns and protocols dictated by the nature of the role itself. The cognitive mechanisms are reflected by the decisions taken by the agent according to the manager orders and the environment (other agents and resources) state *(Figure 6)*.

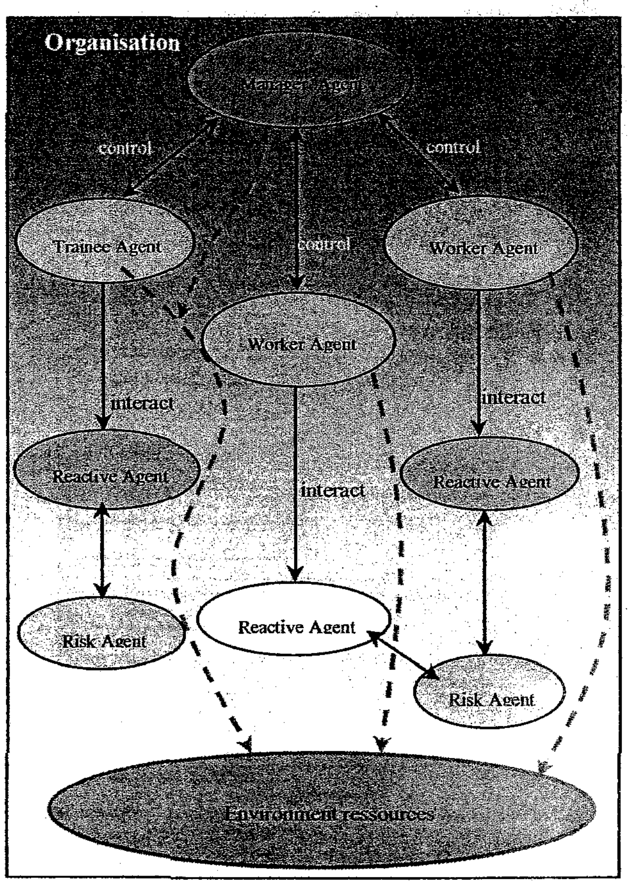

Figure 6 Sructural Organisation

The virtual environment can be viewed as an organisation to which will be connected the multi-agent system. A trace of the environment is needed. It is an open environment. The environment should be accessible, dynamic, non-deterministic and continuous. Obviously, it is a complex system.

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[7] Usine numérique : competitiveness cluster SYSTEM@TIC PARIS-REGION

5. An example of a related previous work

5.1. Context of study

Previous work in the same field had been led in UTC with INERIS, ECI (University of Paris V) and the Polytechnic University of Milan. Partners developed a first scenario representing an operation of pipe substitution in VIRTOOLS environment. The agents evolve in a virtual environment representing a SEVESO site modelled with 3D Tools, depending on the scenario. It consists in a pure animation of succeeding scenario steps (*figure 9*). We can represent a very realistic environment and obtain an excellent visual rendering. With the different virtual interfaces, our system takes another dimension. The user is merged into the environment, in a subjective way. This highlights the utility of virtual reality in such a project and at a higher level the utility of an advanced tool for developing 3D environments.

5.2. Description of the scenario

The task model is the heart of our system (*Figure 8, a, b*). It determines which actions can be done, which interactions and simulations are needed.

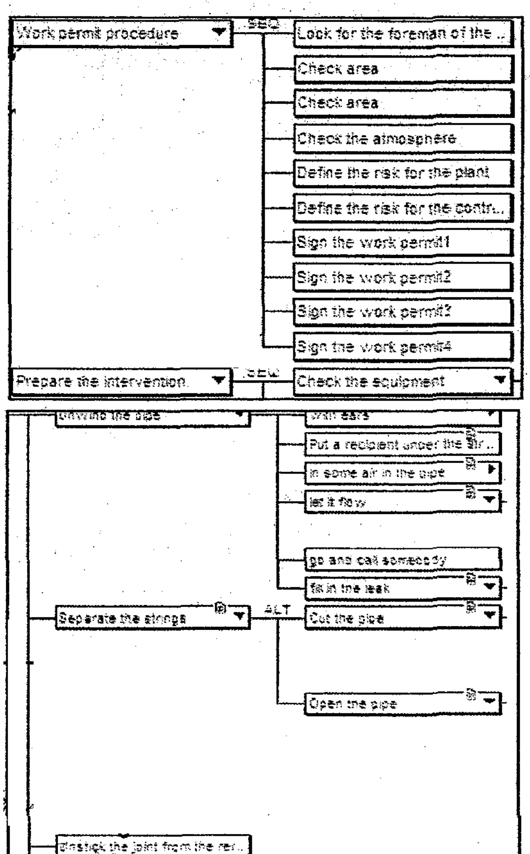

Figure 7 (a) (b) Cognitive Task Model Sample

It describes the activity of an operator in ideal conditions and also in degraded conditions (missing time, imprudent behaviours, safety behaviours, tiredness, etc.).

5.3. An example : scenario progress

We have two agents, a cautious (A1) and an imprudent one (A2). The manager orders A1 to secure the area by installing markers and A2 to uninstall the pipe.
A1 and A2 generate a plan (tasks sequence) to achieve their goal. As A2 is imprudent he will not wait for A1 beaconing to go on the scaffolding. He does not fasten himself and start to unscrew the pipe. He does not succeed, so he decides to go and look for a grinding machine. Due to his imprudence and his lack of knowledge, he does not verify if there is still residue in the pipe and therefore a possible risk is a liquid flow on the floor. If a fork-lift truck driver passes by, he can slide.
To prevent this danger, the safety barrier is the way A1 will beacon the area. If the manager orders a specific configuration, he has to follow it otherwise, as he is cautious he will beacon the area in the safest configuration.

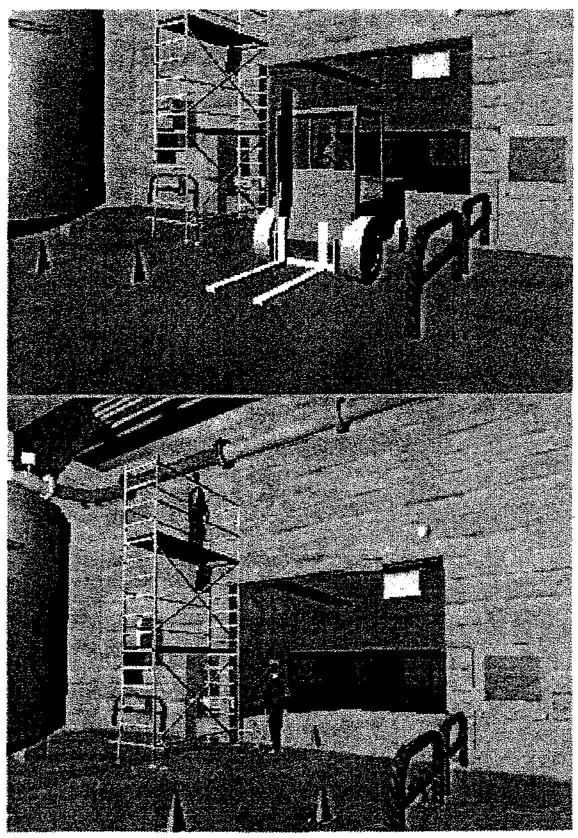

Figure 8 (a) (b) Scenario screen-shots

6. Conclusion and Perspectives

In this paper we detailed the goals and interests of the V3S project. We are developing a system to simulate the operative mode of operators working on a SEVESO site based on a multi-agents architecture: MASVERP (Multi-Agent System for Virtual Environment for Risk Prevention). An interesting part of the project is to work along a new axis: taking a model of risk, a high level model of tasks and a cognitive activity model into account. The goal is to allow managers to visualize the scenario and to view the effects of their decisions in the environment. To achieve this goal we will use a virtual support helping us to give a realistic vision of the process.

Besides, in V3S, this approach will allow to interest better more into human factors:

- ◊ Individual (technical, organisational, human and prescribed aspects) competences
- ◊ Collective competences: understand the procedures, the tasks, the working rules, the role of a working group, the technical or procedural safety barriers, work the communication, the management of an action, the building of a self reliance and a permanent cooperation.

For the trainers, V3S will allow:

- ◊ Quickly conceiving training programs focusing on specifics industrial need (based on feed-backs, accidents analysis, potential risks analysis, tasks analysis audit results),
- ◊ Measuring the effectiveness of the apprenticeship.

Our environment is not only a training environment (VET), it is a VERP, standing for Virtual Environment for Risk Prevention including training and decision making. At present, the system offers the possibility to simulate the operative mode and some risk cases. According to the operators characteristics (safety, imprudent, expert, inexperienced) the system simulate the different associated behaviours.

The results of this work are encouraging. Several issues are left for further work, more precisely we will:

- ➢ Exploit the industrial data to build different scenarios and risk cases
- ➢ Develop the physical module for fluids and cables objects and virtual manikins
- ➢ Coordinate the different basis modules of our architecture
- ➢ Interface the MAS with the virtual environment
- ➢ Build a catalogue of scenarios according to the industrial need (multiple scenarios engine)
- ➢ Construct and coordinate the different basic bricks of our architecture
- ➢ Exploit the industrial data to build different scenarios and risk cases
- ➢ Develop the training module

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