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Minimizing the Risk in the Process Industry by Using a Plant Simulator: a Novel Approach

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The advancement in technology, automation, and mechanization has revolutionized the industrial sector as well as the specific activities of operators. The need for understanding, perceiving and assessing the risk from merely focused on equipment and process, to human (operator) and human machine interaction (HMI) is the aim of this work. The proposed solution allows the operator not only understanding the sensitive zones of the plant, which are prone to higher risk, but also perceiving, training and practicing some key points, which can increase the reliability of both process and operators. Even a minor error or a misunderstanding of either control-room or field operators may put the whole process at higher levels of risk. The paper presents a methodology for the anticipation and reduction to risks exposure in industrial plants. A replica of an industrial plant is developed within a virtual environment facilitated by 3D glasses for stereoscopic vision and 3D spatialized audio for higher immersivity. This arrangement is coupled with process and accident simulators that allow deploying the so called: Plant Simulator. Various normal and abnormal scenarios of industrial processes are developed, assessed, and discussed by means of the virtual environment tool. The operators are exposed to these scenarios through the Plant Simulator in order to perceive and be trained better against risky situations.

1. Introduction

Industrial developments have brought various benefits and comforts to modern life style, nevertheless, the problem of risk and its diversification has also increased. At the same time, the acceptability of risk has also decreased, mainly because of various devastating accidents which took places in last few decades (Manca *et al.*, 2013). The disaster of Bhopal (India) was an eye-opener for the concerned regulation bodies, stakeholders and governments. Since then there has been an evident increase in concern, interest and research on industrial safety. The prosperity and revolution in the industrial sector brought economic, social and cultural benefits that resulted in making the life of men relatively more comfortable (Wall, 2009). However, these benefits came at the cost of processes that are more complex, of technological integration and automation in chemical processes, of more severe operating conditions and reactive chemicals. These complex processes demand for enhanced methods and tools to make the complete system, processes, and operations less prone to hazards and accidents; which can result in loss of production, chemicals, resources and even operators (Manca *et al.*, 2012). An industrial accident can result in the disruptions in workflow, equipment damages, operator injuries, and even deaths (Pariyani *et al.*, 2010). Moreover, an industrial accident may produce severe consequences on the environment and on the population surrounding the plant. In recent years, some of the causes, which can result in accident, were mitigated, but the number of accidents per year is growing. Human error is one of the main reasons for the accidents in various industries specifically aviation and military, nevertheless, process industry is not exempted from this evidence. The role of the industrial operator is to assure smooth operations of the plant. This goal can be achieved better with an accurate and in depth knowledge of the process, relevant hazards, chemistry and impact of the nominal and abnormal operating conditions.
This paper focuses on a novel methodology to improve the conventional training and assessment methods for industrial operators as a step towards mitigating risk in the process industry. The first section presents

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the human errors most commonly done by industrial operators and introduces the concept of situation awareness, which is followed by the details on the Plant Simulator (PS). Subsequently, two main and distinct use-cases are presented to signify the application of the PS. The conclusions section draws the comments and discussion on the possible safety enhancements introduced by adopting the PS to train and assess industrial operators.

2. Human error and industrial risk

Human beings have the inherent ability of making errors. People have their capabilities but at the same time, they have their limitations on attention, memory, task handling, etc. Therefore, the more complex the task is the higher is the probability or possibility for an error, which increases the likelihood of risk prone situations (Nazir *et al.*, 2012a). The excessive use of "technological improvements" has increased the challenges faced by industrial operators. Actually, the pace of progress in technology failed to consider the limitations of human memory and abilities. Human errors in the process industry are generally attributed to factors like complexity of the process, technical system design and the like. In our opinion, the risks involved by the process industry can be divided into two broad categories *i.e.*, intrinsic risks and extrinsic risks. Figure 1 shows a limited number of categories, which can be extended and widened according the required depth of the analysis. We are interested in minimizing the accidents and abnormal situations that may result in human errors by fostering the adoption of the PS paradigm.

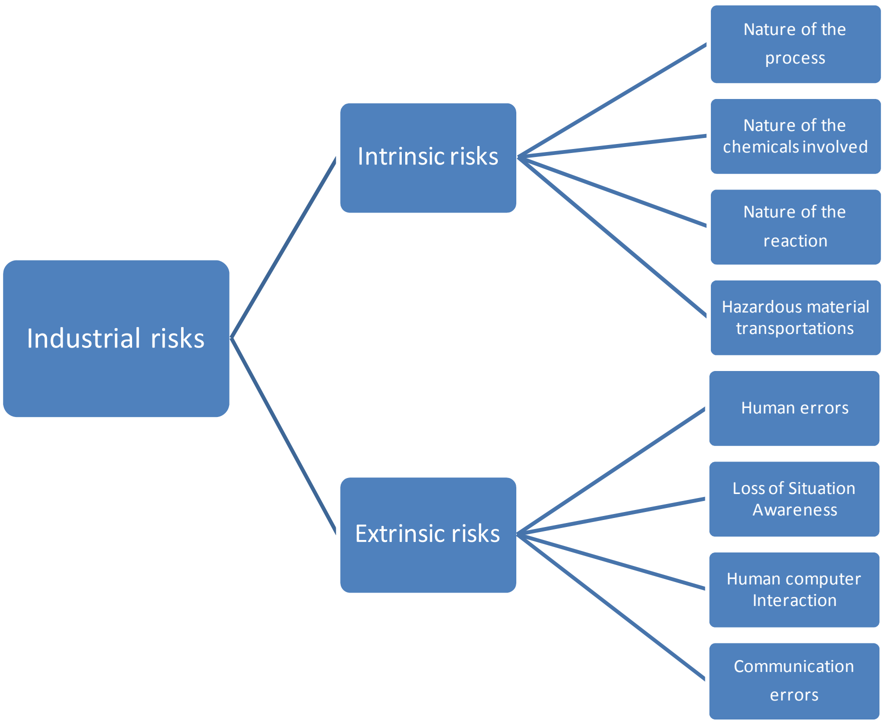

Figure 1- Categorization of risks for process industry.

The topic of human error cannot be considered complete without introducing the concept of Situation Awareness (SA). SA is the term, which was coined by Endsley to describe, as a whole, the degree of understanding, consciousness and decision capacity of people involved in specific activities within specific environments (Endsley, 1995, Nazir et al., 2012a, Stanton *et al.*, 2001).

2.1 Plant Simulator

The proposed engineering solution consists of coupling a conventional OTS (*i.e.*, Operator Training Simulator) with an Immersive Virtual Environment (IVE) (commonly referred to as 3D) that simulates the field in all its facets, spatial sound included (commonly referred to as 3D sound) (Nazir et al., 2012). Such a solution addresses the aforementioned shortcomings by coupling two distinct dynamic software tools: a real-time dynamic process simulator and a real-time dynamic accident simulator. The former simulates the dynamic evolution inside the process units and the pipe network but it is not able to describe what happens outside of the equipment. The latter receives information about the possible releases, outflows, emissions, leakages from the process simulator and calculates in real-time the accident evolution (*e.g.*, how a pool fire or a gas dispersion spatially evolve over time). The dynamic accident simulator quantifies also the effects of the accident on the surrounding equipment, as well as on the involved operators. To close the interaction loop, the process simulator receives as input data the quantities determined by the accident simulator (*e.g.*, thermal fluxes) and determines the effect on the process variables accordingly. In short, the communication between the two simulators is bidirectional as they get influenced mutually. The core benefit of this solution, which is also a breakthrough with respect to the available training solutions, is that the data exchanged between the process simulator and the accident simulator allows:

1. Tracking the dynamic evolution of the process when an accident occurs;
2. Quantifying the possible effects and damages on the structures and the equipment;
3. Quantifying the potential injuries that might be suffered by field operators in real life.

The visual representation of the PS is shown in Figure 2.

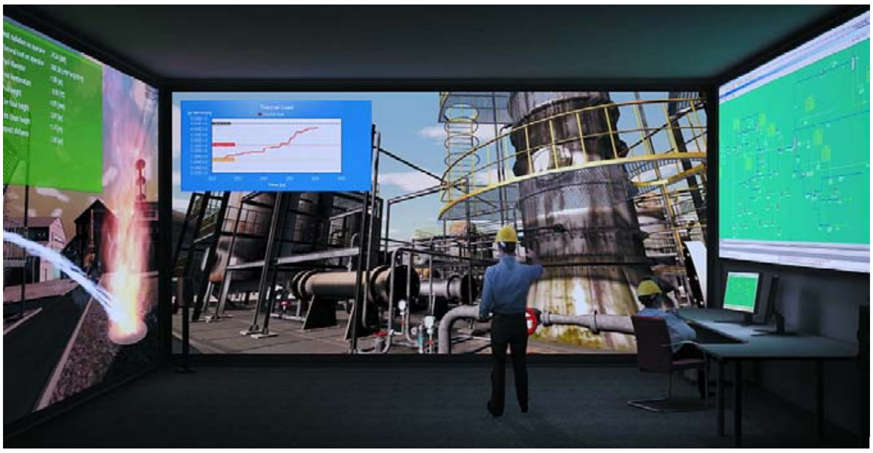

Figure 2 – Representation of the concept of PS (image courtesy of Virthualis company).

3. Methodology

3.1 Training

The ability of human beings to enhance their skills, understanding, comprehension, responsiveness, attention allocation, mental modeling and mental associations can be improved by different training methods. Training is an essential component of industrial safety as it enhances the skill level, productivity, motivation, reliability and commitment among the trainees.
Besides the lack of thorough training evaluations, there is also a lack of training assessment based on exhaustive task, person and organization analyses. A well-designed, effective and efficient training method is necessary for the process industry to mitigate the number of accidents and their impact. Another field, where operator training and assessment are of paramount importance is workers replacement, due to the ageing workforce, in most industrial sites. A viable means of training new and unskilled crews is a common request from process industries. This is also a means to keep process knowledge inside the plant by minimizing the losses due to the retirement of expert workers. These issues call for new methodologies and perspectives in training operators based on reproducible and effective tools. The repeatability of training allows achieving a standardized approach to operator formation and the administering of well-accepted and validated procedures.
For the sake of clarity, the training section of the PS is presented and categorized in Figure 3. The operator meets two hierarchical levels of training. At stage 1, the operator is guided/supported step-by-step to perform the task (on any given section/unit). The training procedure is performed at the best and most crisp operating conditions to improve/maximize his/her process understanding and plant situation awareness. The use and support of colors, sounds, alarms, and visual aids/helps/hints is appropriately chosen to stimulate and enhance the understanding of the operator(s). Once the trainee has learnt to interact and operate within the PS, s/he can undergo at any time a number of exercises and tests to improve his/her skills. Stage 1 of the training hierarchy is characterized by the automatic help and support

of the PS infrastructure that, when necessary, can drive the operator in performing the correct actions and taking the proper decisions. At stage 1, the PS provides also a support when the operator makes any wrong actions by highlighting the device/process unit where the error occurred and by providing suitable and interactive explanations to reproduce but also recover from the wrong action/decision and take the correct one(s).

Stage 2 of the training session of the PS takes the trainee towards a more demanding environment that is closer to the pure assessment stage. Stage 2 differs from stage 1 for three main points:

1. Every action undertaken by the operator has a relative marking according to its significance with respect to the process. The relative marking is based on a deep and extensive knowledge of the process and operating procedures. To determine the relative weights among different actions that contribute to assessing the final mark, one can rely on a well-known and widely accepted methodology such as the AHP technique (Saaty, 1980).
2. The information on mistakes/errors is reduced to the maximum and no special hints are provided to the trainee unless s/he specifically asks for them (see also the forthcoming point 3).
3. Help is provided only if requested, contrary to stage 1 where the program guides the operator to follow and understand the procedures. The trainee is provided with suitable helps and hints that are aimed at explaining how the process works and how the plant is structured. This allows improving the situation awareness of the operator. Moreover, there is a well-defined penalization of the overall mark devised according to the number and level of help requests.

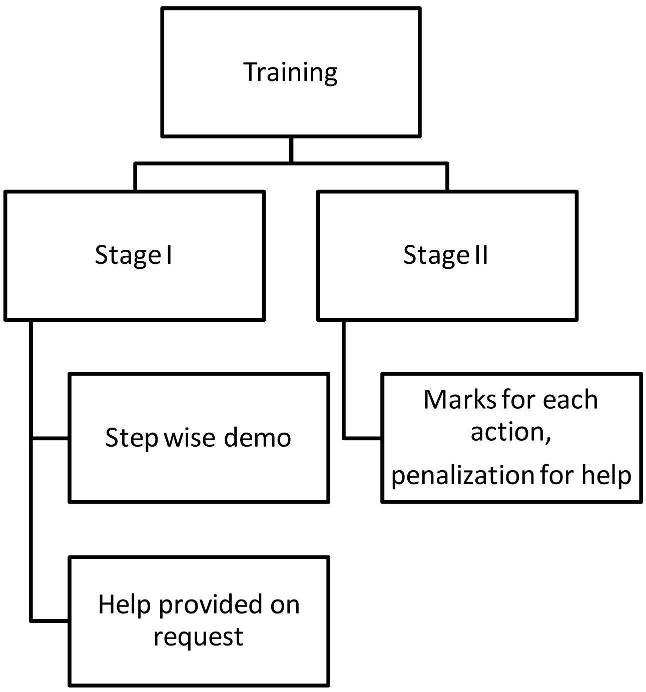

Figure 3 – Stages of training with the plant simulator.

3.2 Performance Assessment

Training procedure and performance assessment are two distinct but at the same time interconnected features of the PS. If the operator assessment is not meant to test the real understanding and skill improvement achieved by the training session, the benefits of training can be refrained from achieving its potential. In recent years some work, as reported before, has been focused on training improvements, however, performance assessment of industrial operators is a topic yet to be dug into and extensively discussed by the scientific community.

The most common procedure adopted by several organizations is the conventional approach to assessment through the direct contribution of the trainer. According to the Authors, a human judgment can be rather weak since it is based on subjective impressions (that can even vary significantly within the same day). Such a biased judgment may vary as a function of both the trainer(s) and the trainee(s) (Colombo *et* *al.*, 2012). It would be then highly desirable to ground operators' assessment on a reliable, repeatable and automatic tool that is completely neutral and avoids any subjectivity. This means that the operators' assessment should not be based on the trainer judgment, which is intrinsically and variably biased. An assessment procedure focused on industrial operators (both field operators and control-room operators) should therefore meet the following prerequisites: consistency, quantitative assessment, repeatability, and neutrality. To reach and satisfy the neutrality feature, the assessment procedure should be automatic and avoid questionnaires and the consequent analysis and correction from examiners. Accordingly, advanced tools for operator training call for an automatic procedure to assess the training degree of operators. This assessment should be implemented in a computer program capable not only of evaluating the marks about the performance of operators but also capable of registering, storing, and analyzing the actions and decisions taken by the operator(s) during the training session. Under this perspective, the assessment procedure should become an algorithm to be implemented in a computer program by means of an automatic procedure.

3.3 Case-studies

The PS not only adds precision to the assessment but also allows defining the parameters of interest with their relative marking. Human beings tend to give equal marks to all (apparent) parameters without considering the relative significance and statistical comparison of single parameters. Therefore, a trainer may make judgments and evaluations according to his/her understanding and experience at the plant site thus introducing the possibility of misinterpretation of the trainee's performance. By doing so, the job assessment of the operator would be influenced by the final evaluation of the trainer. The personal/individual evaluation, especially in presence of some shortcomings, can result in the inconsistent job allocation to an operator who might not be either capable or adequately trained to perform efficiently the allocated task.

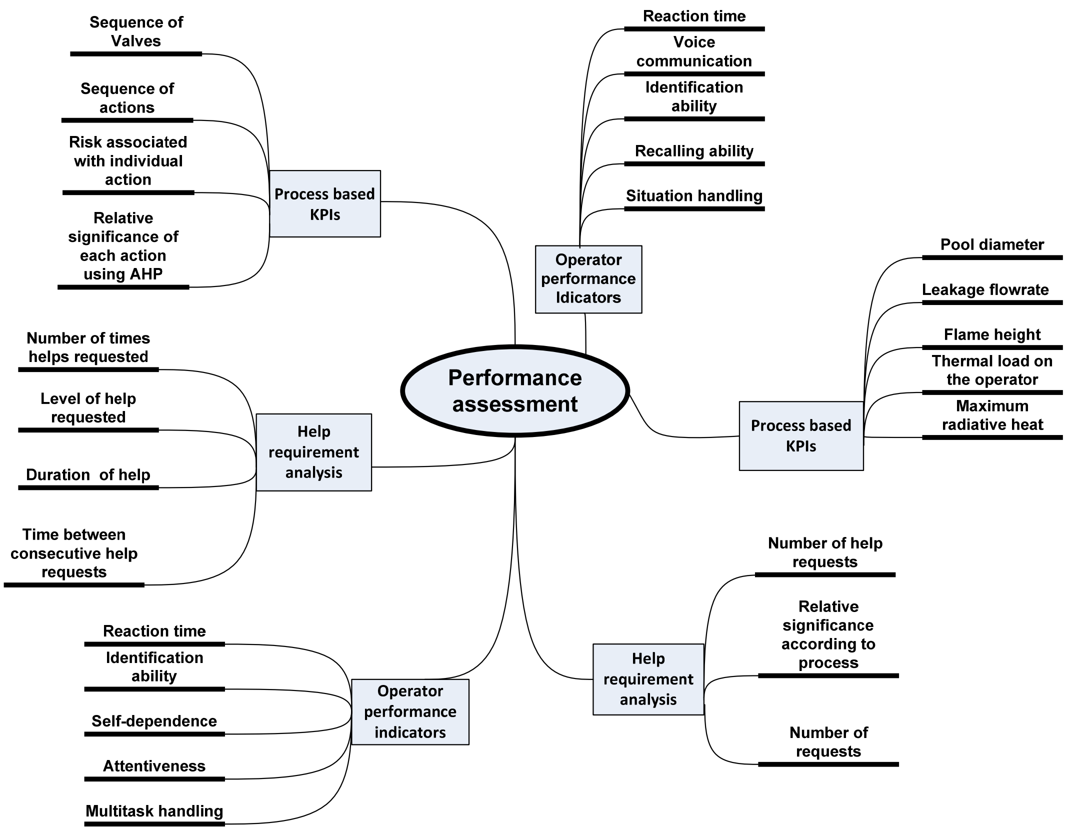

Figure 4 – Methodology of Performance assessment for catalytic inject process (left side) and C3/C4 splitter (right side).

In order to overcome the challenges and reduce the gap between the current methods of performance assessment and the one discussed above, the Authors designed and developed a software tool for the assessment of industrial operators. This tool measures and records in real time a set of process and accident variables, actions, decisions, time intervals coming from the process and accident simulators as well as from the human machine interface of the IVE and determines/evaluates the performance indicators and key performance indexes required to quantify the training level and situation awareness of the operator(s).

The additional benefit of this tool is its inherent flexibility that allows taking the necessary modifications and adjustments according to the needs of the involved plant (sub)sections. To understand this point better, let us take the example/scenario of a butane leakage from a C3/C4 separation section of an oil refinery. The operator is required to perform certain tasks, which can result in mitigating the impact of the accident. The performance assessment algorithm is capable of storing the actions performed by the operator during the given scenario, evaluate the correctness of actions, weigh each action based on a well-defined hierarchy and relative weighing technique (Manca *et al.*, 2012). Figure 4 shows the schematic representation of Performance Assessment (PA) for the example briefly explained above and for that of the catalyst injection procedure of a polymerization process. The right portion of Figure 4 shows how PA takes into account: (1) Operator Performance Indicators (OPIs) based on relevant human factors; (2) Key Performance Indicators (KPIs) based on process understanding and given situation; (3) the quantity/quality of helps requested by the operator. The details on methodology, concept, weighing methods can be found in forthcoming papers.

4. Conclusions

The paper introduced the concept of the PS, which consists of a dynamic process simulator and a dynamic accident simulator interlinked in an IVE. The proposed solution, *i.e.*, the PS, showed its efficiency in improving the overall process safety by empowering the understanding, situation awareness, responsiveness, and decision making of industrial operators, thereby, decreasing the risk of operator error and loss of SA. The assessment of the operators was presented and discussed through the introduction of an *ad hoc* software tool capable of producing automatic, reproducible and unbiased evaluations of the performance of the trainee(s) based on a multidimensional set of KPIs.

The Authors have been running a set of experiments to determine the practical efficiency and impact of the PS on SA and training level of industrial operators. Preliminary results showed how the immersivity feature of PS allows increasing and enhancing the level of understanding and involvement of field operators. When compared to conventional training tools, the PS showed a higher efficiency in forming and achieving a good level of situation awareness.

The paper introduced a number of areas to be further investigated and raised a number of issues that need still to be addressed and finalized. Work is currently ongoing on the implementation of the PS for different use-cases, experiments with real plant operators, impact of training on SA and on possible improvement of the PS with the help of experimental studies and users' feedback.

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