Performance comparison of different training methods for industrial operators

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Abstract

Training is considered as one of the most important components in the process industry. The progress in development of training methods with respect to the increased complexity of industrial processes are still not completely aligned. The role and cognitive tasks of operators are intensified by automation, computerization and mechanization, thereby, increasing not only the complexity but also the sensitivity of the consequences of their actions on the process. Aim of this study is assessing cognitive performance, skills and reactions of industrial operator(s) under abnormal situations as a function of distinct training methods. In particular, in this work, we experimentally analyze two training methods: Power Point presentation and 3D virtual environment. The results showed that the operators trained by means of a 3D environment performed better, when tested under emergency conditions as compared to those trained with other classic approaches.

Introduction

In the process industry, the last two decades have been marked by a significant increase of automation, advanced control, on-line optimization, and supply chain tools and technologies that have significantly increased the complexity and sensitivity of the role of the operator(s) and team(s) (Salmon et al., 2009, Brambilla & Manca, 2012). As in case of many industries, which are saturated with complex human machine interface; human error contributes to the highest number of accidents. The same is true for the case of process industry. The range of accidents caused by human error in process industry is reported in the range of 50 to 75 % (Endsley, 1995). According to Wickens and Hollands (2000) the complexity of industrial processes can be briefly described as follows:

"*The processes are generally highly complex and involve a high number of interacting variables and many degrees of freedom (Moray, 1997; Wickens & Hollands, 2000). Variables can be cross-coupled, so that changes in one variable affect several other variables simultaneously. Modern control rooms comprise more than 5000 displays and thousands of controls and alarms to display these processes (Sheridan, 2006; Vicente, Mumaw, & Roth, 2004). Such complexity can severely*

In D. de Waard, K. Brookhuis, F. Dehais, C. Weikert, S. Röttger, D. Manzey, S. Biede, F. Reuzeau, and P. Terrier (Eds.) (2012). Human Factors: a view from an integrative perspective. Proceedings HFES Europe Chapter Conference Toulouse. ISBN 978-0-945289-44-9. Available from http://hfes-europe.org

overburden the operator's mental model of the status of the plant and makes it extremely difficult for operators to identify the state of the plant. The mental model of the status of the plant, however, is critical for both normal control and abnormal situations (Moray, 1997; Wickens & Hollands, 2000)".

Understanding the complexity of the process by following correct procedures and keeping a good situation awareness, are the important tasks, which an operator is responsible to manage. Measuring and assessing these features is very challenging even during normal operating conditions. However, the added stress and anxiety during an abnormal situation can increase the cognitive load and attention requirements of the operator (Wickens & McCarley, 2008). Unfortunately, the training methods which are employed in the process industry are mostly focused on experiencing the daily operations, (*i.e.*, following normal procedures). Therefore, whenever there is an unusual or abnormal condition, the experienced operators working for several years on the process plant have to cope with this situation only on the basis of their experience and understanding of the process and situation (Colombo et al., 2012). It is almost impossible to train the operator by means of classical training methods for an abnormal situation as there are innumerable situations which can take place on account of changes in specific parameters (*e.g.*, temperature, pressure, level, concentration, etc.). Simulation of the hazards (in real plants), which can evolve as a consequence of an abnormal situation, in a chemical plant, requires huge resources and involve higher levels of risk. However, rare events such as process startups and shutdowns can be simulated virtually a number of times, thus enhancing the degree of knowledge and experience of operators (Brambilla & Manca, 2011, Manca et al., 2013). The idea of employing virtual reality for training the operators of process industry was discussed in the detail by Nazir et al., 2012 and Manca et al., 2012). Another problem in the process industry is the lack of training methods, which can homogenize the level of information among control room and field operators. Control room operators (CROP) are the operators who work inside the control room where process parameters and conditions, graphical data, alarms, process flow diagrams can be seen and manipulated. Conversely, the operator who physically works in the plant and manually observes and verifies controls the parameters according to the requests from the CROP is the Field Operator (FOP).

This paper focuses on the possible advantages of using VR simulation as a training tool to improve the performance of human operators having to cope with abnormal situations. The performance of two groups of participants trained using different methods is compared in a number of given tasks. The key performance indicators (Manca et al., 2012) are identified and evaluated for each group in order to find the effectiveness and efficiency of respective training methods.

Scenario

Oil refineries are of paramount importance in the domain of process industry. Generally, oil refineries are spread over large spaces and consist of various sub-sections which are equally important for continuous production of required products. They are interlinked and interdependent among each other. The hazardous zones of the refineries as more common and extended as compared to other process industries (*e.g.*, fertilizers, pesticides, pharmaceutical, etc.).

The training experiment is performed on the C3/C4 unit. It is an important section of every refinery where the separation of crude oil in to different required ranges (e.g. C1, C2, C3, etc.) is achieved. The details of this process can be seen in detail in literature ((an important and necessary section) of a refinery, which deals with flammable and hazardous liquid. The accident scenario involves an excavator working in proximity of the C3/C4 unit that accidentally hits a pipe in which is flowing pressurized liquid butane (C4). The collision results in a broken flange of the butane pipe with a consequent leakage and the formation of a spreading pool of butane on the ground. After a while an external source of ignition ignites the pool giving rise to a fire. The pool is ignited. The following are the important events, which are simulated.

- C3/C4 plant section of a refinery
- The excavator hits a pipe and breaks a flange
- Liquid leakage from a ruptured flange (see Figure 1)
- Liquid spreading on the ground → ignition → pool fire (see Figure 2)
- The FOP alerts the CROP who interacts with the FOP
- The CROP closes a remotely controlled valve
- The liquid emission is stopped but the liquid level in the reboiler starts increasing reaching the H level alarm
- The CROP asks the FOP to open a manually operated valve (FOV)
- The reboiler level decreases back to the correct value
- The heat radiated by the pool fire to the surrounding equipment does not compromise the normal operating conditions of the plant.

In the scenario pictured above the FOP performance depends on but it is not limited to:

- the time taken to get aware of the abnormal situation and identify the problem;
- the remote interaction with the control room;
- the coordination between the FOP and the CROPs to either remotely or manually close the valves;
- deciding, when requested, whether it is safe to approach the field valve;
- the time taken to move away from the accident site when there is not any further need for intervention;
- alerting, if necessary, the fire-fighters or the emergency team.
- running, if necessary, to the nearest muster point;

Participants and design of the experiment

There were 24 participants (20 males) in the range of 19 to 22 years (average 20.8 years). All participants were students attending the third year of the bachelor degree in Chemical Engineering at Politecnico di Milano, Italy. The participants were all volunteers who had responded to an open invitation (call). To ensure technical understanding, only Chemical Engineering students were selected. The participants were not paid for their participation. The participants were equally divided into two groups and were named group A and group B with respect to the training method adopted, as described in following section.

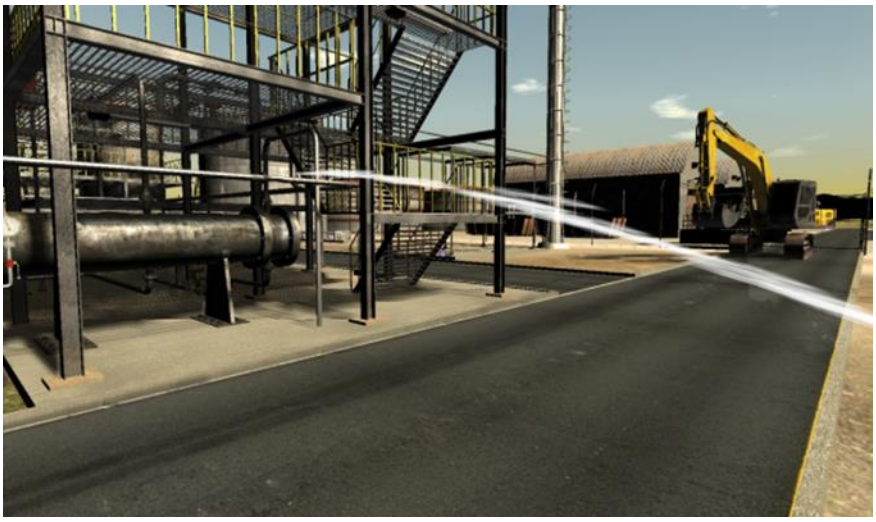

Figure 1. Liquid leakage from the ruptured flange (courtesy of Virthualis Srl).

Figure 2. Pool fire after the leakage (courtesy of Virthualis Srl).

Training methodology

The two groups were trained for the task in different rooms and at different times. It was made sure that no interaction between the groups occurred. Even, the lunch and coffee break(s) arrangements were made separately in order to avoid any interactions between the participants of two groups. Group A was trained in a 3D room with the stereoscopic feature enabled and the participants wore appropriate 3D glasses. Both spatialized sounds and augmented virtual reality were disabled to keep the two training methods at a comparable level. Group B was trained using a conventional Power Point presentation compromising 12 slides. Images from the 3D environment (*e.g.*, Figure 3) were used to prepare the presentation. The training session lasted about one hour for each group.

Experimental task

The 3D immersive environment requires multi-tasking actions. The participants were introduced to the 3D room and were asked to act as a field operator, on the basis of the training that they had received. As the collision of the excavator with the butane pipe took place there was a leakage (*i.e.* liquid jet), which they (participant) are supposed to report to the control room operator. The details of the accident scenario have been already explained in the scenario section.

Once the leakage is identified and communicated by the FOP, the CROP closes the automatic valve which ceases the flow of butane in the pipe, thereby stopping also the outflow from the ruptured flange The FOP is also required to acknowledge the shutoff of the liquid jet and report it to the CROP.

Figure 3. Example of image from 3D model (courtesy of Virthualis Srl).

The next event to occur is the ignition of the pool, which was created because of the leakage. In this situation, the FOP is expected to immediately report the fire to the CROP. The necessary actions (request for fire fighters to arrive) will be then performed by the CROP. The last step of the simulation is a message from CROP to FOP that requires opening a specific valve. The FOP has to identify and open the correct valve, regarding which s/he was trained during the training session.

Results and discussions

Various measures were collected during the experiment in order to evaluate the participants' performance. Each participant was tested individually, and after the experiment, there was a short interview. It was found that the participants who were trained in the 3D environment (group A) comparatively performed better than those of trained with the help of Power Point presentation containing 3D images (group B), with respect to the specific parameter discussed below.

During the experiment, help was provided to the participants as a function of their actions. The level of help was kept consistent for all the participants. For instance if the participant found him/herself lost in the environment *i.e.* getting far from the accident scenario, then s/he was advised to move towards the scenario. This help was given after a specific and constant time interval (*i.e.* 90 s) to keep the consistency among experiments. It was found that the help required by the participants of group A was less as compared to those of group B, as shown in Figure 4. The scenario requires some messages from CROP to FOP (participant). It was found that group B required more repetitions of voice messages for their complete comprehension of the communication (see Figure 5).

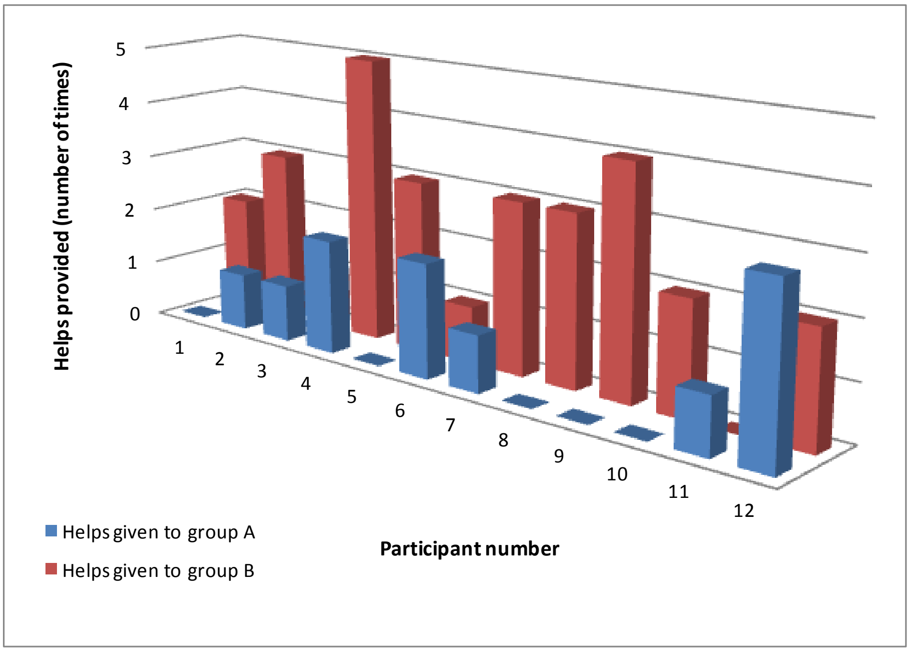

Figure 4. Number of helps provided to each participant of group A and B.

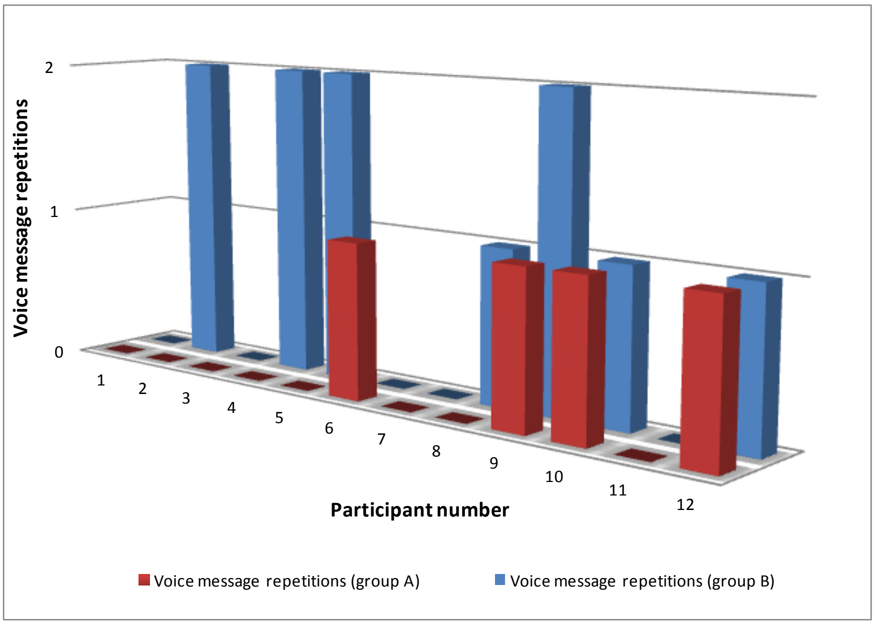

Figure 5. Number of voice message repetitions required for participants of group A and B.

These preliminary results show how a training method based on direct experience of 3D immersive environments shows reaching a situation awareness and process understanding this is decidedly higher than the one obtained by conventional training methods. The two preliminary indicators reported in Figures 4 and 5 quantify the advantages of 3D virtual reality training and its positive feedback.

Conclusions

The current study investigated the effects of different training methods on the performance of human field operators in a simulated accident scenario. The results showed that a training made with help of 3D model of the process plant helps the operators to perform better in terms of response, identification of valves and understanding of voice messages as compared to the performance of operators trained using a conventional method based on a Power Point presentation. Thus, the training which encourages and help to learn complete concept in the 3D virtual model of the relevant section (in this case C3/C4 separation unit) of the process facilitates the operator to understand, comprehend, anticipate and respond better than the those who are trained with conventional method of Power Point slides. Nevertheless, a more detailed analysis of results and further similar experiments will pave the way to deepen the effectiveness of employing the 3D training method at commercial level in process industry.

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