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Impact of training methods on Distributed Situation Awareness of industrial operators

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ABSTRACT

Industrial operators have an important role to play in terms of reducing the probability of accidents by utilizing their awareness and understanding of the system and the situation during normal and abnormal operating conditions. Industrial operators are important barriers against accidents. Distributed Situation Awareness (DSA) has been shown to correlate with positive performance and goal achievement. The role of individual operators as barriers against accidents calls for a greater understanding of DSA in the process industry and industrial plants. Industrial operators must cope with uncertainties with regards to the information they must process in normal and abnormal situations, while working in geographically dispersed locations and with different teams. The significance of DSA during an abnormal situation increases manifold and influences the possible consequences of an accident scenario. Aim of this article is to consider the effect of two distinct training methods on DSA and safety-related performance of industrial operators during an accident scenario. The results show that participants trained with the help of 3D virtual environments ($N = 12$) were able to maintain better DSA and performed effectively within a simulated scenario as compared to those ($N = 12$) trained with a conventional training method.

1. Introduction

In 2011, 539 billion euros worth of revenues were generated from the chemical industry in the European Union alone with the total number of employees being about 1.1 million (CEFIC, 2012). Chemical processes are inherently risk prone. The risk is monotonically increased due to the concentration increment of industries with hazardous productions and higher population densities around exposed areas. An industrial accident can result in the disruption of workflow, equipment damage, operator injury, and may result in several fatalities/casualties. Stark reminders of these risks can be found in a number of accidents, such as the Union Carbide in Bhopal (1984), AZF in Toulouse (2001), BP refinery in Texas City (2005) and the BP Deepwater Horizon rig in Gulf of Mexico (2010). An accident may produce severe consequences for the environment and civil population surrounding the plant (e.g., AZF in France, 2001). The involved companies may also face major economic repercussions (e.g., BP fine after Deepwater Horizon accident) that result in major economic consequences in addition to loss of production and reputation. Measures have been taken to reduce accidents. However, the number of industrial accidents per year is still growing (Pariyani and Seider, 2010) and the possibilities of accidents in the chemical industry are a major societal risk factor. A number of literature reviews have pointed to the main source of accidents as being the incorrect manipulation of process units by the operator(s) (Coleman, 1994; Antonovsky et al., 2013). Kletz (1998) mentioned that accidents occur and reoccur in the process industry because of the inefficient use of information and the lack of learning from the lessons that are available from accident data. As a measure to mitigate the limitations of human capacity, and thus to reduce accidents, automation has been introduced (Woods et al., 2010). Automation, however, brings with it a number of challenges of its own as outlined below.

1.1. Automation in industrial processes

The increase in the complexity of modern process control systems (Hollnagel, 2008; Nazir et al., 2014) which begun with the inclusion of automation-related tools and technologies, has significantly altered the work of process industry operators (Hollnagel, 2001; Norman, 1990. See Dekker and Woods, 1999, for specific examples). Specifically, before the automation era, industrial operators manually intervened in the controlled process.

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Consequently, industrial operators were needed to (physically) gather information about the process and make process adjustments (Emigholz, 1996). As automated process-control systems were implemented, the work of industrial operators was revolutionized from direct manipulation and control to supervisory activities involving the supervision from centralized control rooms (Hollnagel, 2001). For a single operator, some of the complexity lies in the diagnosis of fault situations that require a different approach to problem solving, i.e. an analytic approach that is not needed during normal operations (Patrick and Morgan, 2010).

In complex systems such as chemical process plants, work tasks are distributed among different elements/agents (both human and machine) and correct communication can be vital for the safety of process (Sessa et al., 1999). The operators can be at different sites (physically distant) whilst performing tasks that need coordination to ensure a safe and continuous production. Sessa et al. (1999) and Patrick and Morgan (2010) emphasized that the nature of information, distinguished by being distributed over the whole system and part of continuous collaborative efforts among different agents, can guarantee safe operations. This argument reflects the importance of teamwork and reliable communication among the members of team(s) in the case of industrial processes.

1.2. Teamwork and communication

Teamwork is defined by Wilson et al. (2007) as "a multidimensional, dynamic construct that refers to a set of interrelated cognitions, behaviors and attitudes that occur as team members perform a task that results in a coordinated and synchronized collective action" (p. 5). In the case of process industries, operators are divided into two broad categories i.e. Field Operators (FOPs) and Control Room Operators (CROPs). Typically, FOPs interact with physical devices that are distributed throughout the plant and can thus use some of their senses, i.e. sight, sound, and touch (only occasionally smell and very rarely taste) to crosscheck the perception that is formed by the interpretation of field data from sensors. Conversely, CROPs are typically involved in observing an artificial representation of the real environment, where a number of synoptic displays of the Distributed Control System report the key process variables, which are often complementary to those that are experienced by FOPs (see Fig. 1a and b). In addition, under normal operations, there is periodic communication between FOPs and CROPs to assure continuous and safe operations.

Although both FOPs and CROPs are focused on the same process and equipment, they have different bases for perceiving the environment, understanding the importance of the information (e.g., creating meaning out of the information), and interpreting the incoming information. Process industry is a good example of a complex socio-technical system, where the elements of the systems are geographically distributed, and shared between FOPs, CROPs, and the artifacts with which they interact. During normal operating conditions, FOPs and CROPs communicate on a number of occasions to verify and understand the system status (e.g., operating conditions). As the operating conditions deviate from the optimal range, uncertainties are introduced into the system and normal operating procedures are no longer sufficient to assure the process' safety (Wickens and Hollands, 2000). A different level of problem solving is required by FOPs and CROPs to assess the situation (which falls beyond the normal conditions) and establish a course of actions to eliminate the uncertainties and return the system to normal operating procedures. FOPs, by virtue of being in the field, have direct access to the equipment and can consider the information displayed directly on measuring devices. The CROPs, on the other hand, have access to status information of larger sections of the plant and so use the detailed information from the field to integrate with their wider understanding of the status quo of the system. Under both normal and abnormal operations, FOPs request information from CROPs to gain an extended understanding of the status of the plant section where they are operating, with the aim to enhance their process understanding that comes from the direct (but incomplete) experience of in-the-field instruments and equipment. CROPs, on the other hand, require information from the FOPs to understand what is going on outside of the control room to contextualize the displayed information and add details to the remotely acquired measures. This two-way information sharing is vital to control the processes and preserve the plant safety. Consequently, FOPs and CROPs communicate and coordinate on a continuous basis to weigh and analyze various elements of the situation in order to reach a decision. Therefore, the successful interaction between CROPs and FOPs, enables the responses which can avoid an accident. Unsuccessful interaction, on the other hand, makes the system less safe.

As shown in Table 1, FOPs and CROPs have different information bases on which to form their understanding and subsequent decisions.

Thus, the CROPs' and FOPs' awareness of the process status is based upon substantially different stimuli. The tasks performed by CROPs and FOPs are also not identical in terms of attention requirement, mental workload, responsiveness, and decision-making capability. Furthermore, the information that reaches CROPs and FOPs varies in terms of their nature and sources.

This significant difference in inputs and tasks of operators can trigger misunderstandings and communication errors, which may lead to unsafe and hazardous conditions (Nazir et al., 2012). The accomplishment of a task by a team composed of CROPs and FOPs requires distributed knowledge, collective dynamic understanding, and shared mental modeling (Orasanu, 1990). The task may also be so large and complex that work is shared among individual team members (i.e. a main task is split into sub-tasks). For instance, teams of operators are needed to complete some difficult procedures, such as start-ups and shut-downs, because a single operator or even a couple of operators, e.g., a FOP and a CROP,

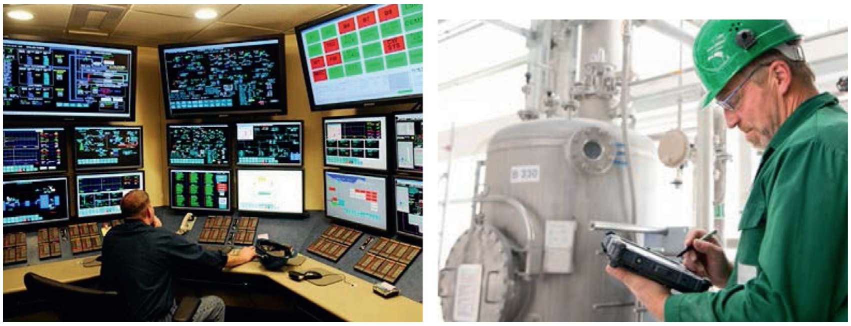
(a) A typical CROP activity
(b) A typical FOP activity

Fig. 1. (a) A typical CROP activity. (b) A typical FOP activity.