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Decision making assessment in industrial process simulation

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Human factors play a major role in process industry to increase safety. The problem of assessing human performance and identify most critical human factors is very complex in a real plant, while simulation in a virtual reality (VR) context provides freedom to test and train for risky situations. On the other hand not all aspects of human factors can be easily assessed in a simulated VR environment. We can distinguish operative skills from more cognitive ones, like, e.g., communication, situation understanding, operation planning, and problem solving. While operative skills could be easily trained and tested also in a real context, communication, command, decision-making and problem solving are more difficult and can be better assessed in a VR context, by controlling the execution of simulation experiments. In this paper we present an approach to assess cognitive human factors to improve safety. The approach proposes a way to automatically detect critical actions and events necessary to assess and measure performances of command and control roles, which can also be extended to measure and assess operative roles performances.

1. Introduction

Human factors are usually considered in the process industry from the viewpoint of the individual operator performances. Most methodologies address this issue from the viewpoint of Human Reliability Analysis (HRA) and are focused on individual or team errors. An example of first generation approach is THERP (Swain & Guttman 1983), which tries to generate probability values of human errors to be used for a probabilistic reliability analysis. An example of a second-generation approach, based on cognitive theory, is CREAM (Hollnagel 1998), whose aim is to provide a reliability interval (a probability of action failure) from an analysis of the tasks to be performed. The cognitive aspect is emphasized by the concept of *control modes*, that can range from scrambled, opportunistic, tactics and strategic, i.e. from less organized to highly planned course of actions.

In both methods, the aspects relative to command, control (briefly C^2) and decision-making are not explicitly addressed. Moreover no methods in the process industry propose explicit solution on how to assess and measure C^2 performances, and are rather focused on assessing and measuring single operator performances.

Kaber and Endsley (1998) on the other hand, consider Decision Making, and in particular the Situation Awareness as the most critical aspect to improve safety.

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The issue we want to address in this paper is how can we measure and assess team performance from the C^2 viewpoint avoiding subjective evaluation as much as possible. We are considering here a context, where an industrial process is simulated in a VR setting, allowing a team of operators (in a Control Room and in the field) co-operates on a given procedure to perform specific tasks. VR simulation allows us to experiment different critical situation, observing how the teamwork evolves, focusing our attention to the most important aspects of decision-making.
In a Command and Control system, decision-making is the most prominent factor, and its *quality* and *timeliness* can strongly influence the overall performance of the teamwork. In a simulated experimental environment, factors that influence uncertainty and time pressure can be easily controlled, changing relevant aspects of the environment in which decision will be taken.
To identify how these factors can be modified it is important to have a clear model of the decision making process from the C^2 viewpoint. Following the "Boyd's loop", Boyd (1986), decision-making is based on a Situation Analysis, so two phases can be considered: first *Analysis of the situation*, which consists of *Observation* of data and *Orientation* (identification of the causes and possible consequences); second *Decision Making* and *Action* where the best tactics is selected and a course of actions taken. The Boyd's loop can be improved on the basis of the research initiated by M. Endsley (1988, 2000) on *Situation Awareness* (SA). It is evident that the quality of decision-making depends strongly on the quality of the SA, in terms of accuracy, completeness and timeliness. Te become aware of a situation, three main stages are therefore needed: *perception* of elements, *comprehension* of the current situation, and *projection* of future possible status. The perception stage depends on cognitive and psychological factors; it is a stage where abnormal events are to be detected, in contexts where multiple disturbing factors can reduce attention level (fatigue and stress, time of day, natural and environmental conditions, etc.). The comprehension stage can require the person to collect further data from the process in order to identify causes and get an understanding of the current situation necessary to figure out, in the third stage, the possible consequences, projecting in the future the evolution of the situation. All three stages are also affected by high level cognitive factors, like person's abilities and experience as well as training, or middle level cognitive factors, like memory or degree of automaticity in frequent tasks execution.
In our view the Situation Awareness stage is the most critical and interesting stage when measuring and assessing C^2 human performances in a process industry context.
Endsley and Jones (2001) have introduced the idea of *disruption* to affect situation awareness. This proposal is very interesting, given the difficulty to assess cognitive performances: a disruption can change the degree of difficulty of a cognitive task, making easier the performance measurement.

2. Situation Awareness in Process Industry

In an industrial process, operators interact with distributed control systems; information comes from sensor systems and alarms that provide a continuous updated framework of the process status in a control room. In the field, besides local instruments, other signals can be detected by an experienced operator. He can observe and hear the equipment and its noise, vibration change or fast temperature increase or decrease, and interpreting them as information on the status of the running process.

When an industrial process is regularly running, deviation from the normal process can quite easily interpreted to update the situation by experienced operators. More critical are situations during the start or stop of a process, like, e.g., starting a gas chilling turbine, or starting or stopping a distillation plant. In such cases a large group of operators are involved, some working on the plant, others in a control room, others waiting for a technical support, or for emergency intervention in case of an accident.

Teams in field and control room are coordinated by responsible, which have the command role and collect all the needed information provided by the equipment, sensors and by other operators. The importance of a high quality decision-making is evident when any abnormal event happens, and the time available to act correctly to avoid major consequences is critical. In this kind of situations, there are three functions to be considered: command function that has the responsibility to take decision by selecting the best course of action and release commands to the involved persons, control function that has the responsibility to monitor the situation collecting data of the process needed to build a correct picture of the situation, communication function that has the responsibility to distribute information among the actors and the distributed control system.

We will focus on the command and control functions, considering the communication function only as a possible source of problems affecting information quality.

From a cognitive viewpoint, the knowledge of the process is one of the most important aspects, and should be considered as a given a priori constraint. The person having the command role should be in principle sufficiently experienced to have a thorough knowledge of all the technological aspects of the process. The mental model of the process is therefore the reference model with respect to which a SA has to be reached.

In such a complex situation the problem of Situation Awareness can be considered from two viewpoints: *individual awareness* of the command role and *shared awareness* when two different persons playing a command role have to share a decision, or even when the whole team has to gain a shared picture to agree on the correct course of action to perform. To reach an individual and a shared SA some difficulties can arise, e.g. failure to perceive cues or signals; failure of interpretation of the signal meaning and to interpret correctly the new situation; wrong picture of the different roles, responsibilities and tasks of the involved operators; failure, wrong or insufficient communication among operators in the different roles. All this factors can influence a single member of the team, thus making impossible to reach a shared SA. In the following we will consider shared SA as the sum of all single individual operator's SA.

3. The problem of performance assessment

Stacy et al. (2004) introduce the concept of PMO Performance measurement objects, to support automatic measurements of team performances; two top level classes of objects are *training entities* (tasks and actors, having specific roles, assigned to tasks) and *observations* (describe the data and measures collected for a training entity). With this approach the authors can assess individual tasks as well as team coordination and mission effectiveness. The examples proposed are mainly focused on measuring the time to accomplish a given task.

In the military context, simulation methods are frequently adopted; a simulated mission is planned, executed (currently using Virtual Reality) and a review of the results is performed after the simulation (*After Action Review*). The after action review can be formal or informal, and guidelines have been published, as, for example, USAID (2006). Anyway the review is subjective being mostly based on interviews and discussions.

Developed to assess air traffic control, the APEX approach, Lee et al. (2005), is based on three main components: a *Human resource architecture*, an *Action selection architecture* and a *Procedure library*. The approach is very effective, since it can also predict operators' performance; the major limit however, is the necessity of a formal description of all relevant elementary behaviors, a practically impossible problem for less formalized problem areas than air traffic control.

Proposals for measuring individual and team SA by Kaber & Endsley (1988) and Endsley et al. (2000) are based on different kind of techniques and methods like: measuring the time to react after a caused event, using e.g. indices like eye movements and tactical communication, subjective situation awareness using SART methodology, modified subjective metrics SWORD, interview and querying operators using SAGAT methods that separates metric in the three main phases of SA.

Research on measuring and assessing Situation Awareness is still on going. Salmon et al. (2009) present a review of most used methods and lists three main approaches: *Freeze probe technique* – stop a simulation and interview operators; *Real time probe technique* – still based on operator's interview without stopping a simulation; *Self-rating techniques* normally applied after trial. All these methods are strongly subjective and no automatic measurements are proposed towards a more objective assessment.

To this aim, measure of merits are to be defined, and they are based not only to the time to perform an action and to react to events, but also to the identification of the actions taken and their correctness and timeliness.

3.1 Disruption to support assessment

In our work we propose to measure and assess individual SA of the command and control roles in a control room and in the field, and using the results to get an assessment of the shared SA of the team. The methodology we are proposing is based on automatic detection of how the two command roles react to given disrupting events, which change the situation in a controlled and pre-planned way. This approach is complementary to methods based on interviews or self-rating.

The measurement and assessment is separately performed for the three main stages of the SA cycle: perception, interpretation and projection, by planning and executing an experimental campaign, where a specific event, called a *trigger*, causes a deviation from the normal process. Command roles need to update their picture, and specific *disrupting* events are activated, making the task more difficult allowing us to observe and measure different roles performances. These experiments are designed to exercise SA in the view of assessing also decision-making quality in particular for the choice of the best tactics to be adopted to solve the critical situation.

4. Designing simulation experiments for Decision Making assessment

We consider disrupting event as factors that influence cognitive aspects of the command and control roles, so we call them Cognitive Influencing Factors (CIF): they should not be confused with the Performance Shaping Factors (PSF) of traditional HRA approaches. PSF can determine a-priori constraints, while CIF are introduced purposely to force an operator to exercise its knowledge and experience when a specific event makes particularly difficult to perform a given task. For example, if we want to assess the interpretation stage of SA, we can disrupt information interpretation by providing dissonant information either from instruments or from other team members. In this situation the operator has to understand what are the correct information to build a picture of the situation. In case the operator is not able to interpret correctly the situation we can stop the simulation or we can continue it by providing some *aid* to overcome the difficulty and continue the experiment to observe another aspect of C^2 performance assessment.

An experiment is based on a pre-defined procedure and tasks to perform; this has to be formally described to allow the automatic detection of operative errors. The design of an experiment is further based on three kind of parameters: *triggers*, to cause a deviation from a normal process evolution; *CIF* or disrupting events, to create difficulties in solving SA or decision-making; *aids*, to help the operator to overcome the disrupting event and continue the experimental session. All three parameters have attributes associated: triggers are relative to some specific plant component for which they assume a value (e.g. a pressure measured by a gauge), the trigger event has a time that identifies when it shall happen and can have a delay time if it is planned to be temporary or permanent during the full experiment. CIF are classified on the basis of the aspect of SA or decision-making disruption role; for SA they can be relative to perception, interpretation or projection, for decision-making they can be relative to prioritization, timeliness, etc. CIF have therefore description and values associated and also an initial time and duration; within this interval the operator is expected to complete his cognitive task, otherwise an aid can be activated. Aids can also have description and value associated and time and duration.

To control the experiment and to guarantee its repeatability, the experiment is described with a script, where all events a pre-defined. When all events have been identified and the experiment is completely described with the script language, also the observables to be measured during the experiment are completely defined. For example a trigger activates a malfunction of a pressure gauge; a CIF is then activated to produce two different pressure values in field and in control room, an aid is also planned to be activated if the command role does not act accordingly to the real situation, for example asking an operator to check the gauge in field or asking other info about the process status. When the experiment will be over, the events logged during the simulation will be used to present a quantitative evaluation of the performance, based on the time to cope with the disruption and to solve the problem and based on the action detected in the VR setting by means of a task tracking technology.

5. Conclusion

In this paper we outline an approach to measure and evaluate the most critical cognitive factors in command and control of an industrial process plant. The approach is based on the evaluation of the performances to reach situation awareness and the quality of the decision-making process of the command and control roles. Specific disrupting events are caused during a VR simulation of an industrial process, necessary to observe the cognitive ability. Actions and events caused by operators during the experiment are logged and provide quantitative evaluation of the level of performances. This approach can be used for training purposes as well as for evaluating the effectiveness of operational safety management e.g. in case some organization or technical change is planned.

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