

Experience Management by Means of Simulator Trainings in High Reliability Organizations

- Re-enacting critical incidents and learning from experience - examples
form nuclear power plants and oil refineries -

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Abstract. *Based on an interview study, we present practical applications of experience management by means of simulator trainings in High Reliability Organizations (HROs) as well as first evaluation results of their usefulness. Experiences which need to be analyzed, stored and disseminated in HROs relate to critical incidents such as malfunctions or accidents caused by human errors that actually did or by chance did not cause severe damages to people or the environment. We describe the process of experience management in HROs, illustrate the use of simulators and report target groups and learning approaches. Finally we summarize the advantages of simulator trainings with respect to three evaluation levels (reaction, learning, results) from different stakeholders perspectives and report the influence of person related variables (such as intelligence, personality and cognitive style) for experience-based learning in such settings.*

1. High Reliability Organizations and Experience Management

Nuclear power plants, coal-fired power plants, and oil refineries are technical systems that require an organizational structure typically referred to as High Reliability Organizations (HROs, see Weick & Sutcliffe, 2003). These types of organizations have to function as reliable as possible because the wrong handling of the plant causes severe damages to the environment or affects peoples lives and health (accidents such as the Three-Miles-Island accident, Tschernobyl accident or the explosion in an oil refinery near

Houston in march 2005, where 15 workers died). The technical and industrial activities of these HROs "are capable of causing perceptible adverse public effects" (Mannarelli, Roberts & Bea, 1996, p. 83). To be as reliable as possible, HROs always expect that their own organizational subsystems and their employees might fail and therefore work hard to avoid failure by learning from experience of former "almost-accidents".

HROs are continuously preparing for the inevitable and train their workers to deal with possible malfunctions so that they can minimize the impact of failures. Besides organizational structure, rules and regulations, and a safety culture, continuous training is one approach in HROs to provide the preconditions for high reliability. In addition to the damages to environment, workers and inhabitants, each day down time causes tremendous costs. In case of an accident or human error that causes the break down of a refinery plant or downtime of a NPP, each day means a loss of approximately 200'000 to 500'000 EUR or even more, which depends on the plant.

Nowadays, more than 90% of the control room personnel for example of all nuclear power plants (NPPs) in all countries world wide are being continuously trained on plant specific simulators (IAEA, 2004).

2. The process of experience management

In HROs, experience management is translated into continuous training of known and former experienced malfunctions and critical incidents. This training is provided by the use of simulator trainings in particular for control room operators and shift personnel. This form of experience management includes processes which Nonaka (1994) calls socialization (implicit dissemination of implicit knowledge, e.g. through on-the-job training or behavioral modeling) and internalization (explicit dissemination of implicit knowledge, e.g., instructed practice regarding how to give employees helpful feedback until the whole task becomes automated).

In practice and translated into to the model of experience management by Kluge (1999) operators and shift personnel report critical incidents to the department of process safety. Their analysis of the incident and consequences for behavioral changes are distributed via internal reports to the shift engineers and simulator trainers. Simulator trainers then use the material for designing training courses and train adequate reaction.

The advantages of re-enacting experiences by using simulators from a learning psychology point of view (Kluge, 1999) are:

- problem based learning: adult learners learn by solving real live problems that occur in their daily work
- adaptive transfer: the experiences that are re-enacted in the simulated work context support the development of mental models that can be used to adapt one own knowledge to solve partly unknown problem, such other incidents.
- identical elements: learners can directly transfer their learning results into their work routines
- lifelong learning: learners are continuously trained 2-3 times a year
- diversity and learner orientation: training groups consists of 2-6 participants only, so that the trainer can relate to and address differences in prior knowledge and tenure.

In that respect, re-enacting critical incidents by using simulator training is safer, more economical and more convenient for adult learners than training in the real system (Flexman & Stark, 1987).

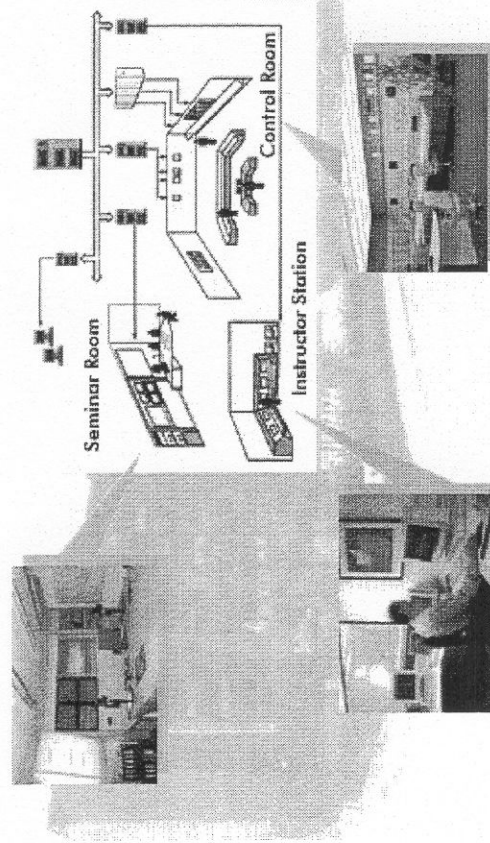


Fig. 1: Simulator of a nuclear power plant (Source: GfS mbH)

3. How is experience re-enacted in simulator trainings? Examples form HROs

We interviewed 12 experts from 12 HROs and collected data on the current use of simulator trainings in German speaking countries of Shell, OMV, BP, Bayernoil, Total, Miro, Kraftwerkssimulator Gesellschaft mbH (Power plant simulator society), the Gesellschaft für Simulatorschulung mbH (Society for simulator training) and the Kraftwerkerschule. In addition, trainers and HR representatives provided training material, documents and brochures, which were also used for the analysis.

Target groups: Control room shift personnel is individually or as a team either trained 3 to 4 times one day per year or one whole week once a year. Frequency and duration depend on whether the simulator is located at the plant or at a central training center.

Simulator types: There are different types of simulators in use for experience management: Basic principle simulators, part task simulators and full-scope simulators.

Accordingly to the IAEA (2004) *basic principles simulators* illustrate general concepts, demonstrating and displaying the fundamental physical process of a plant. The main goal of using a basic principle simulator is "to help trainees to understand fundamental physical processes, basic operations of complex systems, and the overall operation of a plant" (p. 2). The basic principles simulator is therefore associated with *enabling* learning objectives, rather than terminal objectives (IAEA, 1996).

A *part-task simulator* incorporates detailed modelling of a referenced plant but only of some portions of systems, "thereby enabling a trainee to be trained specifically on only parts of a job or task" (p. 2). They are designed for achieving *particular* training objectives associated with specific plant items or phenomena. They range from providing simulation of simple system operation through to detailed fault finding on major sections of the plant (IEAE, 1996, p. 39).

In practice, both basic principle and part task simulators are also referred to as "*generic simulators*".

A *full scope simulator* incorporates a detailed model of those systems of a referenced plant with which the operator interfaces in the actual control room environment. This also includes a replica control room operating console. They are plant referenced and replicate as many systems as possible, including communications, as well as duplicating the actual

control room environment. Generic examples of such simulators exist for particular types of plants where typical conditions are represented while maintaining the dynamics of the system. Some training objectives associated with trouble shooting, fault diagnosis on important systems or reactor protection systems can only be achieved by using full scope simulation (IAEA, 1996, p. 39).

All interviewed trainers of oil refineries use full scope simulators. Most NPPs in Switzerland make use of part task or basic principle simulators, and use full scope simulators in cooperation with other NPPs in different countries, e.g. in the US, in Spain or also in cooperation with the KSG/GfS in Essen, Germany.

The KWS (Kraftwerkerschule, Essen, Germany) responsible for training of operators in fossil power plants owns 5 standard simulators, which replicate standard operations of a power plant. The simulators aren't exactly tailored to a specific power plant as approximately 200 power plants are in use in Germany, e.g. company owned power plants for production sites, which output vary between 10 and 300 MW.

Learning settings: On a general level, there are three types of settings for learning: *basic courses* to train novices, which normally last for several days or weeks, *refresher trainings* for experts, who already worked as operators, and *special trainings* such as malfunction trainings.

Learning objectives of the basic course are the general understanding of functionality, start up and shut down of plants, normal operations, efficient plant operation, and the acquisition of basic declarative and procedural knowledge of the normal operation and handling of the plant, as well as the use of checklists and standardized procedures.

Learning objectives of the refresher or follow-up courses are: Automatisation/compilation of procedural knowledge and use of checklists, maintaining the skill level, and the stamping, embodying and elaboration of understanding.

Learning objectives of the special training (malfunction training) are: consolidation of procedural knowledge of procedures and use of checklists in emergency situation, exercising/practice of unusual situations and reactions to them. *Here the important part of experience management takes place:* critical incidents from the past are re-enacted to (1) acquire a adequate mental model of the functionality of the plant and the history of the incident and to (2) acquire procedural knowledge to be prepared for similar incidents in the future.

For example, at BP Gelsenkirchen, die HRO department gathers information with respect to currently occurred critical incidents, accidents, faults, disruptions or hazardous incidents worldwide, for example the explosion of the isomerisation plant in Texas City in March 2005. Other lessons learned from similar incidents or accidents which were caused by overcrowding and overpressure are added to the information sets which are than distributed to the simulator trainer. That means that the information sets also try to make clear how this incident relates to other incidents, which might have had similar causes and influence factors.

Finally, the information sets contain information about what factors lead to overcrowding and overpressure, which system components were affected, and how the safety systems and functionalities were involved. Then it is asked, in how far this sort of incident could also happen in one of the German refineries. This information sets, the results of these error analysis' and reports of technical investigations then serve as the basic input for designing a training module that explicitly addresses the human side of these incidents. The simulatortrainer then develops a training simulation-based scenario, which sets a setting to re-enact what had happened, to learn how to avoid such an incident. The training starts off with a direct simulator-based experience of dealing with such an incidents and ends with a debriefing of that exercise and additional theoretical background informations.

In an Austrian refinery, the simulator trainer use a "top-ten"-List in which the incidents, which are based on internal statistics most likely to occur are frequently trained.

4. Evaluation of the effectiveness of simulator training for experience management

In a current project in cooperation with BP in Gelsenkirchen, we investigated the benefit of simulator trainings from the stakeholder points of view by interviews and training experiments. We interviewed 20 control room operations, 5 shift engineers and 4 members of the board.

Because up to now no quantitative data is available from the referencies and plant, we had to rely on personal experiences reported by the interview partner.

Accordingly to the training evaluation criteria (reaction, learning, behavior, results) by Kirkpatrick (1959) simulator training affects mainly three evaluation levels:

- Reaction level: Operators report a gain in self-efficacy, self-esteem and stress resistance. Operator report, that because of the simulator training, they feel more self-confident in their daily tasks, because they do not need to be worried about sudden incidents which they can not handle. The simulatortrainings are perceived as a valuable asset to constantly refresh knowledge, skills and abilities for their daily tasks. Form them it seems to be the only possibility to train this kind of incidents at all. Most of the control room operators would like to take part in simulator trainings more often. They also remark, that a high physical fidelity is a very important precondition for a high learning outcome.
- Behavioral level: Supervisors report a higher operating safety and faster start up and shut down of plants, and therefore an increase in equipment and plant availability. In one case, the start up phase of a particular plant was only half as long as the estimated time. Control room operators find it hard to explicitly tell, how they use the acquired knowledge skills and abilities in their daily work. This might be due to the fact, that this sort of training-based experience management methods remains on a implicit level, which is difficult to verbalize and to directly observe on an intra-personal level.
- Results level: Supervisors report higher revenues and value by more effective and optimized start-up phases and the energy saving normal running of the plant. The optimized start-up, which was practiced in the simulator, for example lead to an earlier full use of the plant and therefore an earlier production start. Especially the energy costs for normal operation phases were lowered. Nevertheless it almost seems impossible to find quantitative measure and to quantify the non-appearance of an incident.

In additional training studies, we found that the positive effects of simulator trainings were affected by person related variables and the training methods. We found interactions between person-related variables such as intelligence, cognitive style, error orientation attitudes and personality, self-efficacy and learning motivation with certain trainings methods such as error management Training, drill and practice and overlearning. For simulator training design, this means that experience management needs to consider the personal attributes of the learner more strongly.

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