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ScienceDirect

Procedia Manufacturing 3 (2015) 1519 – 1526

Procedia MANUFACTURING

6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015

Towards effective training for process and maritime industries

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Abstract

With the development of technological innovation, many industries such as process and maritime industries constitute more complex automated systems, dedicated operating conditions, multilevel interconnections, as well as human-machine and human-human interactions. The actions and decisions made by operators and seafarers affect the safety and productivity of these systems. It is wellknown that around 60-80% of the accidents are attributed to human error (directly or indirectly). Generally, each operator or seafarer is must undergo training before starting their real jobs. In recent decades, emphasis on operator training has increased – resulting in advance training simulators with several features like immersivity, stereoscopic sounds, hydraulics, and even use of different odors. However, the design of training methodology can have a significant impact on the skill acquisition of trainees. The growth of integration of technology in existing systems as well as newer systems is much higher than that of improvement in training methods. Unfortunately, there are few studies linking the training needs and the real-world demands on operators, revealing a significant research gap to fulfill.In socio-complex systems, it is necessary to consider various aspects in the training methodology, which can facilitate the operators/seafarers to handle normal and abnormal scenarios adequately. This paper provides a background of current training methods through analyzing the process- and maritime industries as illustrative examples, highlighting the limitations associated with each of different perspectives (technical, psychological and organizational) to propose an training syllabus that allows for learning by experience and interaction with scenarios of different complexity. It consists of a three-stage hierarchy with increasing demands concerning technical and relational complexity and time pressure. The training is centered on handling real-time operations with increasing complexity starting from basic components of the process, advancing to real-time operations, and reaching high technical and relational complexity that needs to be handled in situations with limited time and uncertainty in data. The challenges that arise in team-working tasks are also considered in the conceptualization of the training syllabus. The proposed training syllabus includes training content, objectives and performance evaluation criteria.The systematic methodology of performance evaluation will allow practitioners to obtain transparent, unbiased and consistent certification of trainees.

Peer-review under responsibility of AHFE Conference

*Keywords:*Training; Safety in complex systems; Systematic training syllabus, Performance indicators

Peer-review under responsibility of AHFE Conference
doi:10.1016/j.promfg.2015.07.409

1. Introduction

Independent of the operations and nature of industrial processes, the attention on industrial safety has increased in recent years [1]. The increase in automation and integration of advanced tools in systems resulted in heightened complexity of the tasks that operators are expected to perform in their daily operations[2].Maritime and process industries are two types of safety critical systems. Such systems have the potential hazard of loss of life, significant property damage or damage to the environment. These systems are capable of huge production (process industry) and transportation (maritime industry),still, the reliability and consistency of these systems are questioned whenever an accident occurs. Human error is believed to be a contributing factor in more than 80% accidents in process industry and more than 90% accidents in the maritime world[3; 4]. This paper is focused on possible improvement in human skills by introducing a systematic training syllabus adapted to the work domain characteristics and the demands placed on the human operator.

The recent era in Human Factors research have brought significant developments in the occupational safety, which were not considered necessary in past[5]. It is well known that standards of safety have improved over time as the awareness of humans to understand the concept of safety has increased. The increase of control loops and robust software solutions have (somehow) enabled the automated control of internal and external variations. Still the losses on account of accident the world observed has not been significantly reduced. According to the International Labor Organization (ILO), the estimated total costs of occupational accidents and work-related diseases worldwide are 4% of the Gross National Product (GNP). Given that the total GNP of the world was estimated to be approximately USD 34,000 billion in 2003, it follows that the annual worldwide cost of work-related injuries and diseases is approximately USD 1,360 billion. In terms of human lives, the picture is all but encouraging as about 2 million people are killed by their work every year, thus on average 5,500 people is killed at work every day.The bleak figures above highlight the need to find measures and methods that help reduce the number of accidents. Comparatively fewer efforts have been made to facilitate the human, who is the most adaptive component of systems[6]. Improving the performance of systems by focusing on safety performance[7]. Several theoretical and empirical studies have suggested that operator training improve the performance of operators during normal operating conditions as well as in abnormal scenarios. The performance of humans can be honed by using several techniques. One of them is well designed training. Formalized training in the maritime domain can be traced back a number of centuries[8]; however, the challenge is the adaption of training according to latest challenges faced by these sectors. This can be achieved by moving towards a theoretical framework of systematic training, which shall be later investigated empirically over a longer horizon of time to determine the consistency of such framework. This paper is an effort to propose such a framework based on the literature available and experiments conducted in the laboratories on training and performance assessment.

2. Current training practices

2.1. Process industry

The implementation of operator training has been growing in the process industry[9; 10]. Although there are not universally accepted methods for training operators in process industry, it is deemed necessary that operators go through training before embracing the real plant operations. The recruitment of operators varies significantly depending on the geographical location of the plant, safety culture, safety standards and availability of manpower. The duration of training phase varies; however, the philosophy of training has similarity among various regions [11]. Generally, a trainer is an expert of the chemical process, its details, dynamics, operating conditions, interconnections, control loops, as well as malfunctions and troubleshooting. The training starts with conventional lectures and PowerPoint presentations. In recent years, the use of Operator Training Simulators (OTS) is getting popular. Typically, the OTS is a software tool, which is able to simulate chemical processes in real time and is installed in a dedicated room that replicates the control room with all its necessary furniture and features. Moreover, training sessions for malfunctions, troubleshooting and team training are considered in some industries. Nevertheless, the knowledge of trainer regarding the learning habits and existing learning theories is limited, which can refrain the trainer to deploy the training facilities at their maximum level. This limitation can be overcome by developing a systematic training syllabus, which will be discussed later. For further details on current training methods seeSalas et al. [12] and Kluge et al. [11]

2.2. Maritime industry

The training of seafarers have been practically oriented with young boys often enlisting at the age of 12 where they performed a range of duties concerned with the operation and upkeep of deck department areas and equipment. They were rated as seafarers when they were 16 years old having mastered all skills associated with their rank. To rise to the rank of an officer the sailor had to pass an examination of all aspects of seamanship. Training of seafarers was very much "on the job" and long durations of service were required to prove one's worth[8]. Today, the training of seafarers is still practice-oriented, but much of the basic training is done at nautical vocational or higher educational institutions. The training of seafarers and maritime officers at vessels larger than 500 gross tons is governed by the International Maritime Organization's Standards for Training, Certification and Watch keeping (STCW). The STCW describe the minimum competence requirements that seafarers must have before they can be given certified seafarers. Still, there is currently no tradition for evaluation of competence of seafarers after certification. Requirements involve Proof of Participation (e.g. hours, days or months aboard a vessel; see e.g. Emad and Roth [13]) rather than Proof of Competence (actual skills, knowledge and attitudes). Today, much training occurs on bridge- or machine room simulators. The assessment of these operator´s performance is usually done by individual subject matter experts that subjectively determine if the observed actions of the operators are sufficient to be accepted.In addition, the majority of simulator exercises is focusing on routine operations – and few training systems are focusing on the handling of abnormal or critical incidents.

3. Limitations of current training methods

Unfortunately, the pace in increase of complexity in process and maritime industries was higher than that of improvement/up-gradation in training methods, which resulted in evident gap between training needs and demands of operators, some of which are:

1. lack of realism in training (e.g., immersive environments, virtual reality)[14];
2. lack of simulated abnormalities and accidents[1];
3. lack of team training[15];
4. lack of objective performance assessment[16];
5. lack of integration of technological tools to aid training/learning phenomena [11];
6. lack of non-technical staff training [17];
7. lack of generation of data from training simulators [18];
8. Lack of scenarios imitating abnormalities and malfunctions[1; 3];
9. Lack of integration of results and research from other domains where safety and training are relatively more developed (for instance, process, nuclear and aviation industries)

To overcome some of the above-mentioned challenges in training a systematic method of training operators is necessary. The conceptual framework is discussed below:

4. Proposed training syllabus

This section proposes a training syllabus that demonstrates how the training can be designed based on the state-of-the-art in training research. The proposed training syllabus is composed of three stages of increasing complexity (interconnectivity and dynamics) and is mainly aimed at inexperienced operators/seafarers, in which operators experience several scenarios to expose them to instances that need to be learned to acquire relevant skills. Such stages are centered around the core part, which is the handling of real-time operations with an increasing complexity starting from a more "static" perspective on stage 1 (in order to arrange learning of the basiccomponents of the operations), succeeding to stage 2, addressing the "normal technical complexity" as in normal and real-time operations, and reaching stage 3, with a high technical and relational complexity involving abnormalities and accident scenarios. This approach is also named "increasing difficulty" in which experiential learning starts with a simple version of the task and gradually increases its difficulty as learning progresses e.g. by increasing time pressure gradually[19]. Therefore, after going through all of these stages of training, the operator can be considered competent to start working on the plant on tasks which match their level of competence for normal as well as abnormal operations.The training syllabus suggests that carrying out a particular action of the real-time operation and then seeing the effect of the action in this situation should initiate the learning process. The second step consists in understanding these effects in the particular instance, e.g. in low, medium or high-complexity scenarios in stages 1-3, so that if the same actions were taken in the same circumstances, it would be possible to anticipate what would follow from the action, e.g. in predicting future states. Stages 1 and 2 are interlinked and integrated using scenarios of increasing complexity (see Fig. 1). The training for the understanding of the process components is also centeredon the handling of real-time operations.

First, the operator is introduced to Flow Diagrams and relevant process details before encountering with the system (plant operation or relevant marine operations) in the training simulator. This allows the trainee to gain an understanding of the basic scheme and layout of the process and systems. This is the first stage of training. The operator learns about the process details, control loops, process control techniques, unit operations, and unit processes (in case of process industry) and the seafarer learn about theoretical and practical navigation, map usage, and perform simple navigation and maneuvering tasks. The additional feature of this training method (i.e. with training simulator) is the possibility to evaluate the outcomes of individual training with the help of automated assessment criteria (see Manca et al. [18] and for further details). Moreover, the selection of performance indicators is subject to the depth and stage of training. For instance, stage 1 requires performance metrics aimed for normal operating conditions. The first stage is aimed in proving a complete picture of the tasks to be handled during normal situation to the operators/seafarers. The first stage aims to provide a detailed understanding of the normal operation of a process plant or the routine operations during maritime navigation such as following the Collision Regulations (COLREGS) or the proper use information to ensure safe and efficient navigation. Table 1 provides a summary of the stage 1 training syllabus in the form of training contents, objectives and associated and performance indicators. For instance, in the case of training for a refinery process, stage 1, reflective observation and formation of abstract concepts, is mainly focused on the process parameters, details, dynamics, control algorithms, and so on.

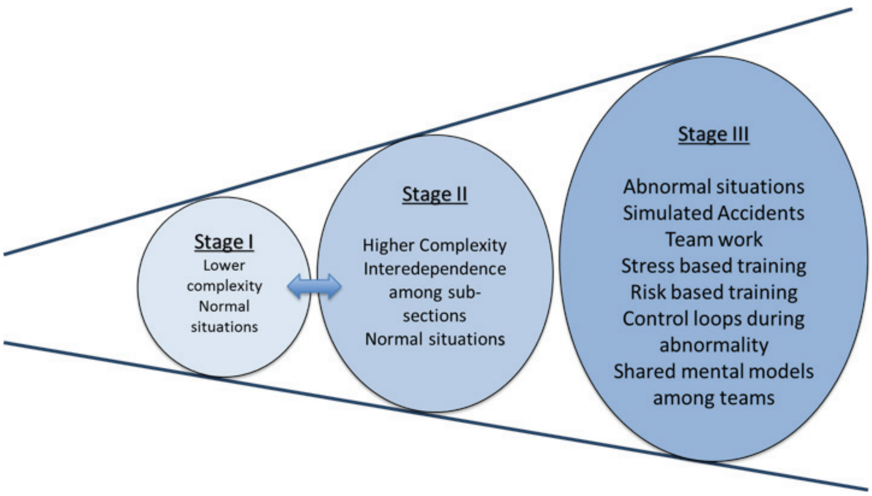

Fig. 1: A proposed training syllabus based on three stages, from lower to higher complexity.

Table 1. Stage I of proposed training syllabus.

Training content	
Stage 1	Testing in new situation: • experience a walk-through in training simulator (process or vessel) • experience replica of real process and scenarios with rich details • applying communication drills among teams from distant locations Concrete experiences: • performance of all sequences of actions • acquires skills by means of cross-training among operators (and seafarers accordingly) • exercises reflecting distributed nature of the complex systems • exercises for identification of alarms and their respective locations Observation and reflection on: • process details with relevant complexity Formation of abstract concepts: • relevance of distributed agents in the system
Training objectives	
Stage 1	• technical and understanding for normal operations • an understanding of the multi-agent systems for normal operations • a mental map for normal operations • an understanding of alarms and their basic management • a shared mental model among operators/crew • understanding labels and codes distributed around the plant
Relevant Performance Indicators	
Stage 1	Assessment of: • correct actions • correct sequence of steps • reaction time • exchange of messages among operators/seafarers • multitask handling • identification of codes distributed around the plant/vessel • alarm identification

The second stage of training focuses on interdependencies between sub-systems and between different aspects of a maritime operation in order to allow trainees to connect the simple works and procedures within the whole of larger routine work tasks such as staring up/shutting down of process plants or coastal navigation in congested waters. In both of these tasks the understanding of the individual sub-systems' role within the larger system is of vital importance for successful performance. Table 2 summarizes the features of stage 2 training. The trainee experiences a deep insight into the specific pieces of equipment to better understand the individual parts and the complete picture of the process. For the maritime domain this relates to how vessel hydro dynamics and propulsion plants affect the maneuverability of the vessel. The situational stage 2 highlights the interdependencies and linkages between stage 1 and stage 2 and shows how basic skills learnt in stage 1 are utilized in more complex work tasks/operations.

Table 2.Stage II of proposed training syllabus.

	Training Content
Stage 2	Testing in new situation: • acquires insight into individual sections, equipment, or component of the vessel/plant) • exercises reflecting interconnections between various subs-systems Concrete experiences: • practice of exercises reflecting interconnections between various subs-systems and procedures Observation and reflection by: • zooming in to the subsystem (inside) to observe and understand all relevant parameters. Formation of abstract concepts: • individual sub-system understanding and knowledge • specific function/features of sub-systems with respect to the complete systems • optimal range of each subsystem

	Training Content
Training objectives	
Stage 2	• an understanding of individual sub-systems • necessary operating conditions for optimal function of each sub-system • an in-depth understanding of locations of agents involved in systems and their functions • understanding codes and labels associated with each subsystem
Relevant performance indicators	
Stage 2	Assessment of: • subsystem knowledge • subsystem (and agents involved function and significance) • correct actions taken for a safe operation • exchange of voice messages among operators • multitasking handling • identification of codes and labels

Stage 3 of the training syllabus allows the operator/seafarer to face abnormal situations and accident scenarios. The advancement in training simulation has allowed to conceptualize and implement various malfunctions and abnormalities in the simulated environment, which would be impossible to simulate in reality. The trainees are exposed to various possible abnormal situations and are trained to analyze and handle them by taking necessary actions and as well as by communicating in a precise and effective manner. Therefore, they can learn about maintaining high awareness and alertness during abnormal situations and accidents that can avoid the full deployment of the accident scenario during real operations. Knowledge and/or experience of previous abnormal- or near-miss scenarios can enable a human operator to recover the system to normal state – thereby avoiding an accident altogether. As shown in Table 3, the performance indicators are selected according to the nature of the abnormal situation and accident simulated. These arrangements allow the trainee to understand his/her possible errors during the abnormal situation. It is worth highlighting that training for abnormal situations and accident scenarios is only feasible in the training simulator (for details seeNazir et al. [3]) given the obvious ethical and economical concerns associated with staging a true accident scenario.

With some modifications in the concept and depth of training and assessment methods, the syllabus can be adapted and tailored for the experienced operators (as a function of their experience and background). The duration of the proposed training syllabus can vary according to the complexity and capacity of the process as well as of the operators' experience.

Table 3.Stage III of proposed training syllabus.

Training content	
Stage 3	Testing in new situation: • experiencing the simulation of various abnormal situations • experiencing the simulation of various accident scenarios Concrete experiences of : • safety actions • abnormal situation management • hazard identification Observation and reflection of: • abnormal situation handling • accidental scenario handling • simulated alarm flooding Formation of abstract concepts: • mental models and emotional coping strategies for various accident scenarios

Training content	
Training objectives	
Stage 3	• handling abnormal situations, communicating during stressful situations • coping with process uncertainties • using artifacts, e.g. in stressful situations • diagnosing faults • using their mental model to interpret possible uncertainties • operators acquire knowledge of the technical aspects of abnormal situations.
Relevant performance indicators	
Stage 3	Assessment of: • knowledge concerning impact of abnormal situation • responsiveness • speed and accuracy of fault diagnosis • alarm reaction and response • stress handling • reporting and communication • handling alarm flooding

Some limitations should be highlighted. The proposed training syllabus is a proposal and theoretical framework to encourage the researchers and practitioners for the development of specific syllabus for training and capitalize the proposed framework. The advancement in training simulators can be best deployed by investing in the methodology and framework of training. A series of experiments can improve the reliability and consistency of the syllabus proposed here. In addition, stage 3, which involves stress exposure training by simulating accident scenarios in the training simulator, does not guarantee the simulation of all possible accident scenarios for any specific process. The aim behind stage 3 is preparing the operators to handle stressful situations at the plant to enable the operator to handle any abnormal situation, known or unknown, in a professional manner.

Based on state of art knowledge a training syllabus is proposed by considering the advancements in process and maritime industries, challenges faced by operators and seafarers, limitations of existing training methods and importantly training for improvement in safety (i.e., stage III) as well as performance indicators for the evaluation of training are also included in the training philosophy. Further details and insights of the proposed training syllabus will be covered in forthcoming extended paper(s).

Acknowledgements

The first author acknowledges the vital intellectual support of prof. Annette Kluge in conceiving some of the ideas presented in this paper. The discussions with prof. DavideManca and Dr. Linda Sorensen have also helped in improving the manuscript.

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