Importance of Simulators, Systematic Approach to Training, and Integral Instruction Centres in the Process Industry

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***Abstract*— Due to globalisation, present challenges of process industries include increasing their competitiveness. One way to address these defies is by investing in the training of plant operators. Traditionally, operator training was done informally through on-the-job techniques and has been improved trough time. Simulators were included as a part of training and have proved to be efficient and effective. It has also been found that their use results in savings caused by availability, thermal performance, plant life, and environmental compliance of the simulated processes. Despite its benefits, a simulator does not guarantee a successful training unless a program based on a systematic approach to training is used; this maintains a continuous improvement in the stages here proposed (analysis, design, development and support, integration, implementation and evaluation) considering the simulator explicitly. Having an integral instruction centre with adequate personnel and material infrastructure is helpful to exploit both, simulators and training system. These centres, among other things, must be designed so that the simulator may: exchange data with modern commercial external programs to support the training program; consider the evolution of simulators technology (for example, with immersive or non-immersive virtual reality); and expand the simulators considering analysis and optimisation capabilities. A review of the present situation of all these topics is exposed in this paper.**

Keywords-training; systematic approach to training; operator training simulator.

I. INTRODUCTION

In Mexico, the Advanced Training Systems and Simulation Department (GSACyS [1]) is a group of the Electrical Research Institute (IIE) specialised in the development of operators training simulators (OTS), training systems, and computer-based testing systems interconnecting simulators and real equipment. GSACyS has more than 35 years of experience and has primarily developed simulators for power generation plants but it is making incursions in the petrochemical industry. Some of the simulators are full-scope: a Nuclear of 650 MW; a Thermal of 300 MW; a Geothermal of 110 MW; a Gas Turbine of 150 MW; a Combined Cycle of 450 MW; and a geothermal of 25 MW (two of those are available online). Other simulators are portable in order to test real plant equipment like Voltage Automatic Regulators or Hydraulic Control Systems of Generation Plants. GSACyS has also developed training systems for virtual reality and one simulator for the traffic control of the underground transport system of Mexico City. IIE has been a pioneer in the area of OTS in Latin America since 1979 [1] and has remained active with new developments. Just recently, Argentina [2] and Brazil [3] have initiated the development of simulators.

Currently, the process industry in general is facing intense global competition and increasing regulations. These factors are changing the nature of work, the requirements of knowledge and skills that workers need in order to perform their work. This represents a major challenge that industry needs to overcome.

The process industry has increasingly addressed this challenge through investment in training and development of human capital for the purpose of having efficient and skilled labour. It recognises that improving the safety of operations, increasing the efficiency of processes, the quality of work, and the compliance of specific objectives; rely on having personnel with solid knowledge and proven skills. It also recognises that having a workforce knowing the operational needs of a process results in benefits to the safety of workers and therefore to the economic aspect of the business. For example, oil companies are aware that the lack of specialised staff significantly affects in the development of operational activities, security, and the economy of the company [4].

The aim of full scope OTS is to reproduce the behaviour of a plant, reflecting the dynamic values of the variables displayed on operating consoles. OTS are an important tool to support the training of operators of a process plant, but insufficient without an Integral Instruction Centre (IIC).

II. TRAINING METHODS IN THE PROCESS INDUSTRY

There are several training methods in the industry. They can basically be divided into two types [5]: on-the-job and off-the-job. The former has always been used by the industry in a natural way and refers to techniques such as direct instruction from experimented persons (with no educational skills); this includes direct instruction, job rotation, special projects and field work visits. The latter has been implemented since the second half of the last century and includes techniques such as classroom courses, computer-assisted training provided by third parties and the use of simulators.

The Safety Health and Environment Executive Office of the United Kingdom (UKSHE) conducted a study about company training [6]. The companies involved reported that most training was done on-the-job and only 23% made reference to training in emergency situations (of which only 3% used a simulator). This occurred despite the fact that literature concerning operator training emphasises the importance of high-level skilled operators.

[1] Some acronyms are after the name or phrase spelling in Spanish

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In a recent revision [7], a statistical study was conducted to US companies stating that 33% of the industry uses application-related simulators for personnel training to some degree. A worldwide survey conducted by ARC Advisory Group [8] found that nearly 28% of companies claim to use OTS. However, these results could be misleading. ARC believes that this relatively large reported percentage reflects the fact that this was a survey regarding OTS and industrial companies probably did not report their real training methods.

Some people of older generations have developed skills and knowledge needed to live comfortably with the speed of technological change. However these opportunities are mainly available to people with a certain level of education. Unfortunately, at least in Mexican government production companies, most operators have a low educational level and their positions are in most cases awarded by promotion ladder situations rather than on merit and work capacity. In April 2015, only 69% of the Mexican workforce had completed middle school [9].

During the ’80s and ’90s of the last century, the people known as "Generation Y" or Millennial were born [10]. One of the defining characteristics of this generation is to have an addiction to technology; they have always been surrounded by PC’s, internet, smartphones and have constant changes in their technology. Continuous exposure to technology has represented a lifestyle and, with it, an approach to learning. This younger generation learns more efficiently with related technology than with traditional methods. According to the U.S. Bureau of Labor, in 2014, 50% of the workforce belonged to generation Y [11]. In terms of age this index should not differ significantly worldwide.

Recent studies continue mentioning the fear of change [12, 13, 14]. Some that are of particular interest for this paper are the change that represents operating a new process and changes due to modernization of process with new technology. This fear is usually mentioned in general and no references were found regarding statistical differences between the attitudes of older generation and generation Y employees (although we may assume that fear is greater in the older generation). These studies agree that one of the factors that minimise the fear of change is that the operator already masters his new tasks. One way to ensure this mastery is by training with the help of OTS (and perhaps preferably coexisting with traditional methods).

III. Advantages of Having a Training Simulator

Some advantages of the use of OTS are:

- Ability to train staff in equipment operation in different normal operating conditions such as start-up, shut-down and load-changes according to operational procedures, without interfering with the real production process.
- To reduce risks of causing damages to the actual plant equipment when operating under scenarios outside of the recommended operational range.
- To help improve the skill and sensitivity of operators making decisions when real extreme situations occur.
- Ability to train operators during equipment or control element malfunctions and high impact transients; situations that cause a high stress to operators.
- A wider range of staff can receive effective training, eliminating the risks and gaps present in on-the-job training, and the possibility of self-training (with tools designed for this approach).
- Ability to improve the operations and profitability of equipment by reducing failure risks related to human errors during their operation.

A cost-benefit analysis of OTS is difficult to estimate, especially because “what would have happened if…” situations should be addressed. Nevertheless, in a classic study on power plants simulators in the United States [15], the benefits of simulators were divided into four categories of savings: availability, thermal performance, component life of the plant, and environmental compliance, totalling $4,500 per installed MW. This means an investment recovery of about 3 months for developing a simulator. This study has been implicitly extended to other industry areas in order to justify the use of simulators. Thus, the National Institute of Standards and Technology (NIST) and the Abnormal Situation Management consortium (ASM) encourage the use of simulators [16, 17]. They have determined that 50% of abnormal situations are due to human error and estimate that incapacity of control systems and operating personnel to control abnormal situations in the process industry costs the US at least 20 billion dollars per year. A major justification for purchasing an OTS is the ability to review the control system and provide operators with a better understanding of the process [18]. By using the simulator, operators acquire the confidence to regain the nominal operating status of a plant after a trip (shut-down) or to properly operate the process; significantly reducing the costs associated with having the plant out of service or operating in less efficient conditions.

British Petroleum estimates that its simulators have saved 20 million dollars over 5 years and have recovered 20 times their investment [19]. In Mexico, over a period of 14 years, the use of simulators for training operators estimated savings of $750 million for power plants [1]. In the Geothermal Simulation Centre (CESIGE) in Mexico, according to their statistics, the number of trips provoked by human error and the percentage of these in relation to the total number of trips fell from the start of their training program [20]. The operational cost of the training centre is lower than the cost of energy not generated due to trips caused by human errors (Fig. 1). Similarly, a case study was presented where, in just one year, the number of trips of a cooling tower was lowered from 15 to 0 when the causes of human errors were identified and an OTS was used as a tool [21]. A particular mention should be made to the US Administration of Occupational Safety and Health (OSHA) that explicitly recommend the use of OTS [22].

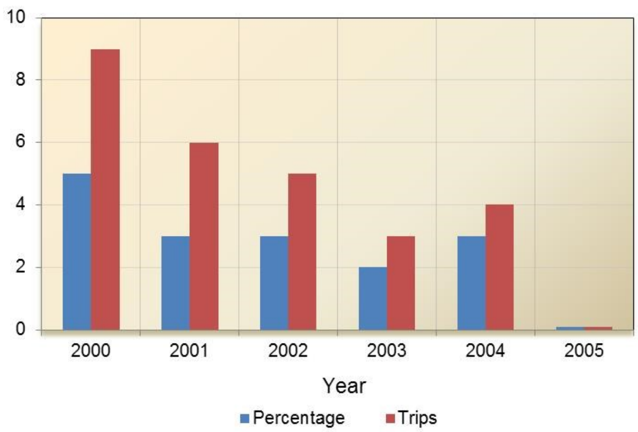


Figure 1. Human error trips and percentage relative to the total.

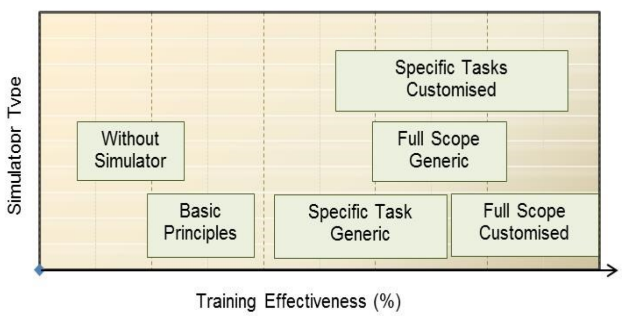


Figure 2. Training effectiveness versus simulator type.

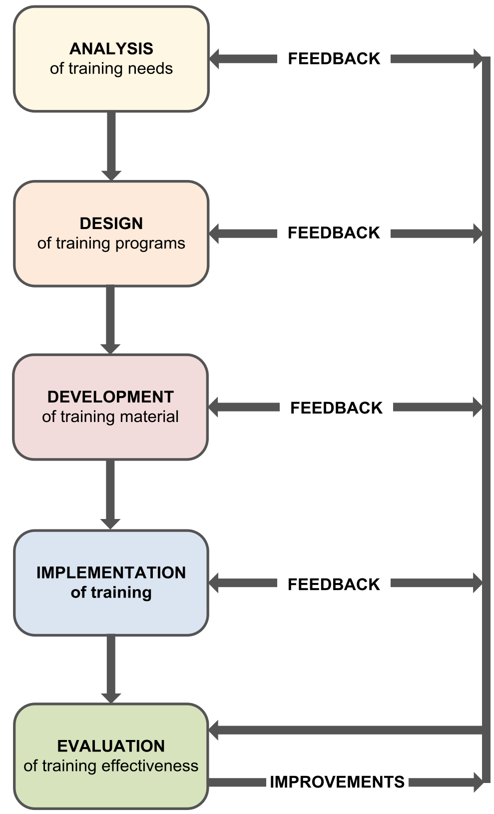


Figure 3. Original overview of the SAT process.

With 35 years of experience in the development of simulators for training operators and considering some other similar ideas [23, 24, 25], IIE's perspective is that the effectiveness of training depends on the type of simulator available. We can summarise this scope in Fig. 2 which is only qualitative and based on common sense. The effectiveness in *x* axis is subjective and has been not really measured by us. As an example, note that simulators for specific tasks (generic or customised) is below its full-scope equivalent, as it only trains staff in a specific system and does not complete an overview of the systems and their cause/effect in relation to other plant systems.

IV. Systematic Approach to Training (SAT)

Maximising the benefit of the OTS requires an organised and comprehensive training program that optimises the use of the simulator and operator job performance [26]. OTS by themselves do not guarantee that the operator becomes competent; it needs to go together with a suitable training program which follows the "MakeMeThink" educating methodology [27]. For the simulator training to be successful, attention must be paid to the maintenance of the simulator, the creation of new instructors and a good development of training materials [28].

Even with a generic simulator, if a SAT is used, it could be possible to obtain better results than with a full-scope simulator by itself (at least in some specific tasks) [21].

A good training system should consider its available tools. The simulator can be the basis of a training program and is always susceptible of improvements, from tuning its behaviour to the addition of new simulated systems or update according changes on the real plant. It is therefore important to review of the simulator scope regularly and methodically.

The SAT has its origins during the Second World War. It was used for the efficient development and deployment of new equipment and weapons systems [29]. This system is currently based on five stages: analysis, design, development, implementation and monitoring, and evaluation (control). Apart from some adaptations, it has essentially remained the same over seventy years. The adoption of the method for the processing plants was initiated by the nuclear industry and supported and extended by the International Atomic Energy Agency whose original scope (presently in use) is presented in Fig. 3 [30].

A good training system should be based on SAT with OTS considered as a vital factor. In Fig. 4 a slight variation of the SAT may be appreciated. It was adapted to process plant operators, according GSACyS point of view. The idea is to consider a simulator as a fundamental part of training and be included in the SAT process explicitly. OTS have been included in SAT programs of leading world institutions but have been not considered as an especial item in the SAT definition [30, 31, 32, 33, 34, 35]. The proposed process considers continuous improvement whose main tasks are:

- Analysing the training needs and objectives.

- Designing the training plan according to the available tools.
- Developing instructional material, simulator scenarios and the tutorial program tracking system (students' progress).
- Inspecting and acquiring new teaching materials and qualifying instructors in the pedagogical area.
- Integrating all the tools in a consistent program to operate in the most convenient way.
- Conducting the training program including its control (tracking system).
- Evaluate each part of the program and its overall effectiveness and efficiency.
- Identify and implement potential improvements arising from the evaluation.

Following this concept ensures that operators are prepared in the best possible way to fulfil their tasks.

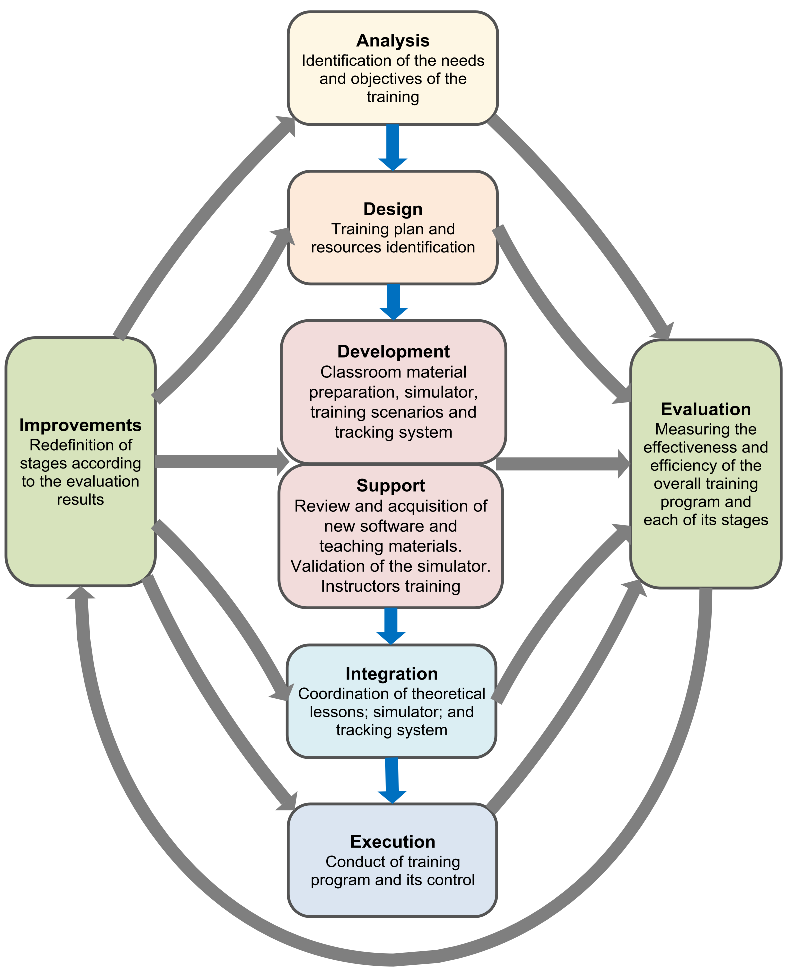
Nowadays the benefits of a systematic approach to training (SAT) cannot be put in doubt. In fact, the process companies lacking a SAT may be at a disadvantage with respect to other enterprises.

V. Importance of Integral Instruction Centres

The literature has many examples of the advantages obtained by using OTS and different ways of implementing a SAT. GSACyS considers that having an IIC where the necessary infrastructure is available, it is the best manner to exploit SAT and OTS in an optimal way.

An IIC is a physical place designed ad hoc for training necessities. The personnel involved must have 100% of their time on tasks associated to the SAT, presented in Fig. 4, to ensure updating their teaching methods continuously. The GSACyS experience has shown that involving operating staff in the work of the training centre, as one more responsibility of their tasks is not a good idea; they always tend to give more importance to production than training.

An IIC should be designed to provide students (or operators) the necessary training within an environment with no distractions. It is most convenient to have the training centre outside the plant where operators have their daily work. If this is not possible, it should ensure that students are not disturbed during their study time. This is an important factor (not frequently mentioned) that impacts positively on the effectiveness of training. Nuclear power plant industry has OTS (and as a consequence IIC) as a compulsory part of its training program, but there was not found any reference to IIC in other industries.



GSACyS proposed scope of systematic approach to training.

VI. Situation in Mexico

PEMEX and CFE are the oil and electricity government companies in Mexico, respectively. A recent energy policy has been approved and both companies will gradually allow private inversions during the following years. This fact will change the present situation for sure, but by now, CFE with more than 60,000 employees, has three IIC with about 13 simulators. The underground transport system of Mexico City has one IIC. All these centres have been installed with the support of OTS developed by IIE. PEMEX, with more than 147,000 employees, does not have a single IIC with OTS. PEMEX has simulators to analyse its process but they are not used to formally training operators [36].

To the knowledge of GSACyS, Mexican private industries, excepting CERREY [37] have not IIC based on OTS, at least installed in Mexico. GSACyS continues expanding CFE training capabilities and has a program to offer OTS developments to private companies and PEMEX.

VII. Future Of The Operators Training Simulators

Processes companies are currently investing in the integration of OTS in their conventional corporate training programs [26]. An important part of this scheme is to develop simulators using communication standards to share and exchange data with modern commercial external programs that will support the training program.

Links between OTS and the actual plant scenarios developed for virtual reality (immersive or non-immersive) play an important role in the training of potential operators. When the simulated scenarios link operator actions in the control room with what happens on the virtual equipment, it allows the operator to raise awareness of the impact of their actions. Also, workers in the field know what effect causes their manoeuvres in the control room. Undoubtedly, the widespread awareness of a process leads to better teamwork and improves work processes. The term used since long ago to designate the Operators Training Simulators is OTS and the importance of modern methods is suggested by the use of the novel term ITS (Immersive Training Simulators) [38].

The increasing use of Internet and the availability of higher bandwidth now allow the possibility of using simulation applications on line (such as those mentioned beforehand, developed by IIE). In [38] even the possibility of running simulation applications on mobile devices is mentioned.

Extra tools to support actual plant operators like intelligent systems; data displays for heat rate; efficiency calculation; etc., should also be part of the simulator and the simulator must be prepared to adapt and reproduce them. In fact, a simulator must be designed to be able to adapt and use any software that could be acquired in real process plants. An example of this is presented in [39] where a new tool to plan a system recovery after a blackout in a power grid simulator developed by EPRI was adapted.

OTS are typically designed to have a process model behaviour equal to the reference plant (response associated with the instrumented variables). Training of operating personnel can be substantially improved if the OTS is expanded to have analysis capabilities. This means that the simulator may predict with a high degree of confidence the behaviour of a process including the variables not instrumented and eventually in conditions outside the normal range process operation, including changing the design parameters.

Another aspect not yet completely covered by present OTS is the optimisation of operating conditions according to several objective functions defined by users. For example, in power plants working in different load percentages, it may be desirable to compliance the environmental regulations requirements or assure the turbine operation is in certain range while trying to have generation costs as low as possible for a required amount of produced MW.

VIII. Conclusion

Simulators for operators' training are being used more often in the process industry in general due to their role as a support in savings for availability, thermal performance, plant life, and environmental performance of its associated plant processes. Usefulness of OTS is evident and process companies without them are at a disadvantage.

It was detected that a simulator itself does not guarantee a quality training if you do not have a systematic approach to training, material development for training needs, and especially constant surveillance and maintenance of the simulator scope and the global training process. All these tasks require hard work. Simulators for operators training and systematic approach to training are encouraged to be coordinated in an integral instruction centre to ensure the success of a training program.

The link with emerging methods derived from new technologies and the simulators be enabling to be continuously improved to cover more aspects to increase the quality of the operation of processes should also be considered.

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