DEVELOPING RESILIENCE SKILLS THROUGH SCENARIO-BASED TRAINING: A COMPARISON BETWEEN PHYSICAL AND VIRTUAL SCENARIOS

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Abstract. The aim of this study is to present a new application of a method for developing resilience skills (RS) through scenario-based training (SBT). This application used virtual scenarios for training hydroelectric power plant operators. Based on this, it was possible to compare the results with an earlier application of the same method for training grid electricians, using physical scenarios. The SBT method adopted in both contexts consisted of: (i) identifying RS, work constraints, and actions for redesigning the socio-technical system; (ii) developing template scenarios; (iii) developing protocols for undertaking the simulation and assessing trainees´ performance; and (iv) testing and refining the scenarios and the protocol. The different simulation technologies are compared, stressing implications for the training of RS.

1 INTRODUCTION

Contemporary sociotechnical systems (STS) are characterized by their complexity, resulting from factors such as the growing scale of operations, intense use of information technology and a changing external environment (ElMaraghy et al., 2012; Carayon, 2006). Under these conditions, resilience is essential in order to compensate for the difficulties created by complexity. Although complex sociotechnical systems (CSS) are resilient by nature, conditions that favour resilience can be created by applying suitable managerial and technological practices.

This article addresses training in resilience skills (RS), a practice that can support individual, team and organizational resilience. Scenario-based training (SBT), in turn, is a means of developing RS since it enables the simulation of realistic scenarios, providing systematic and structured learning experiences as well as an appropriate measurement and feedback system (Zendejas et al., 2010; Salas et al., 2008).

As such, the objectives of this study are twofold: to present a new application of a SBT method for RS development proposed by Saurin et al. (2014); and to compare two types of technologies for SBT, one using physical scenarios and the other applying virtual ones. This discussion is based on case studies of the electricity sector.

2 CONTEXT OF THIS STUDY

Training using physical scenarios was conducted in an electricity distribution company, focusing on the work of grid electricians carrying out emergency maintenance on the grids. Virtual training was carried out in an electricity generation company, focusing on the work of hydroelectric power plant operators.

The SBT method adopted in both projects consisted of the following stages: (i) identifying RS, work constraints, and actions for redesigning the STS (ii) developing template scenarios; (iii) developing protocols for undertaking the simulation and assessing trainees´ performance; and (iv) testing and refining the scenarios and the protocol. This method is described in the study by Saurin et al. (2014), which reports the application of SBT in the aforementioned power distribution company using physical scenarios. The present study also consists of a new application of that method, in a hydroelectric power plant using virtual scenarios.

3 OVERVIEW OF THE WORK CARRIED OUT BY GRID ELECTRICIANS AND HYDROELECTRIC POWER PLANT OPERATORS

Concerning *the electricians from the emergency maintenance teams,* demand for services of these teams usually starts with phone calls from customers to the Customer Service Call Center, which sends a service order, via a computerized system, to the operations center. Then, the central operations control room analyses the information and contacts the team that are nearest the place where the call came from.

The teams are formed by a pair of electricians, who await a call from the central operations in vehicles in different areas of the city. Typically, a customer's request is about power shortage and, sometimes, due to damages to the infrastructure of the distribution network, such as rupture on the power line.

Concerning the hydroelectric power plant operators, two operators per shift control the dam from a control room within the dam structure itself. One operator served as the command room controller and remained in the plant's control room for his entire shift, primarily responsible for the supervisory controllers that operate the power generating turbines. The machine room operator is responsible for inspecting plant sites and measuring equipment performance, as well as manually operating machinery when necessary. Thus, while the control room operator stays in the control room the whole shift, the machine room operator leaves the room periodically to inspect the power plant or manually operate equipment.

The hydroelectric power plant used as a reference in this study for the development of the simulation has three Kaplan turbines generating a total of 136.8 MW. The dam is 856.25m long and the reservoir covers 63 km² (considered a run-of-the-river plant), with seven surface and three underwater floodgates.

4 TRAINING PROGRAM DEVELOPMENT

4.1 Resilience skills, work constraints and actions for redesigning the socio-technical system

Cognitive Task Analysis (CTA) was used to identify RS, work constraints, and actions for redesigning the STS (stage i), involving interviews (Critical Decision Method), observations of actual work and document analysis (table 1). Wachs et al. (2012) present details on the process of data collection and analysis for stage (i).

Table 1. Data sources

	Power distribution company	Hydroelectric power plant
Interviews	13 interviews with electricians (done with pairs of electricians, total of 24 different participants) ≈20 hours of audio	8 interviews with operators ≈9 hours of audio
Observations	20 hours of field work 30 hours of training course	40 hours of field work (control room and machine room)
Document analysis	work instructions, standard operating procedures, safety procedures, job-related responsibilities, incident reports	work instructions, standard operating procedures, safety procedures, job-related responsibilities

In the case of grid electricians, 12 RS categories (with 105 examples, which account for practical examples of RSs, so workers could find them meaningful and easy to understand), 14 constraint categories and 15 actions for redesigning the socio-technical system were identified. As for hydroelectric plant operators, 11 RS categories (69 examples), 6 categories of constraints and 7 actions for redesigning the socio-technical system were identified (appendix 1).

Although the study in the hydroelectric power plant identified fewer RS and constraints, this does not necessarily mean it is less complex than the electricity distribution context. On the one hand, the work carried out in these plants takes place in a more controlled environment with less direct influence from factors such as population and difficult access. On the other hand, activities at hydroelectric power plants involve a significant number of dynamically interacting control parameters, such as voltage, flow, floodgates, river levels, and climate influences. For example, 795 command operations were incorporated in the computer platform for the training scenarios.

Regardless of differences in the number of RS in both contexts, there is a similarity in their nature, such as for RSs related to work strategy: "draw up work strategies to re-establish power plant operations" (hydroelectric operators) and "draw up work strategies after defects have been identified" (electricians). In both cases variability is inevitable and therefore the need for dealing with events that are not fully covered by standard operating procedures is part of the routine.

4.2 Template scenarios

In stage (ii), template training scenarios were devised with the support of electricians and hydroelectric power plant operators. Template scenarios present the core characteristics required to meet training objectives. Thus, work constraints can be added to template scenarios in order to increase the level of complexity of training sessions (Martin et al., 2011). 3 template scenarios were devised and implemented for the electricity distribution company (physical SBT) and 4 template scenarios for the hydroelectric (virtual SBT). Table 2 presents one scenario for each context and describes its main elements.

For the physical SBT, a network was built, with eight poles, one transformer, and five meters, each simulating one residential client. A tension of 127 V energized the grid and kept bulbs lit up in each client. In order to work in those scenarios, trainees received a vehicle equipped with materials, tools and safety gear.

The computer platform for virtual SBT was developed based on photographs, videos, and sounds (e.g. alarms, vibration of turbines) from a real hydroelectric plant and it accurately depicted the power plant setting. In addition to this, a logical mathematical model was designed to operate the plant, similar to the power plant's actual operating model with 795 commands.

Table 2. Main elements of SBT

	Physical Scenario	Virtual Scenario
Initial Condition	Technical information: Oscillating light in boxes 30 and 50, crossbar 4 or light oscillating in box 50. Consumer information: fridge “does not start”, electric shower “does not heat up”.	Technical information: ancillary service in generator unit (GU) 3; machines in the system: GU1 (bar I with 40MG), GU2 (bar I with 40MG), GU3 (connected to bar II at 40MG); General Information: time of day: 3 p.m.; climate: fine weather;
Defects/ Problem	Distribution point connector incorrectly sized, defect in the neutral cross connector.	GU3: temperature of 70°, heat exchanger and oil circulation pump in the bearings
Proposed Solution	Change the connectors	Stopped for urgent / emergency work “Request" machine so that stoppage is for urgent (and not emergency) work.
Resources Materials	For the scenario: low voltage grid with five consuming units and s transformer (fig. 1) For learners: equipped truck	Computer platform (software/hardware: LabVIEW, Java and PostgreSQL) (fig. 2), rooms and radios.
Human Resources	Actors: DOC (Distribution Operation Center) and consumer; Trainees: 2 electricians	Actors: Operator from the Operation Control Center (COGE), supervisor (coordinator) and maintenance Trainees: 1 machine room operator and 1 command room operator.

4.3 Protocols for undertaking the simulation and assessing trainees´ performance

Simulation and assessment protocols (stage iii) aimed to: guide the instructor in conducting the simulations, record simulation data and assess the simulation itself and the trainee performance. The simulation involves the following steps: (a) briefing: opening the simulation session by explaining the training objectives and presenting a general overview of the simulation process; (b) the simulation itself, either physical (figure 1) or virtual (figure 2); and (c) debriefing: once the simulation is completed, the instructor and trainees discuss their performance and learning opportunities, followed by a self-assessment whereby trainees assign scores on a questionnaire and instructor's evaluate the participants based on the same questionnaire.

The debriefing plays a key role from the resilience engineering perspective since it allows the identification of new examples of RS, new work constraints and new actions to re-design the system. In fact, the debriefing is an opportunity to discuss the performance of the joint cognitive system, going beyond the trainees´ individual performance.

The protocols for undertaking the simulation and assessing trainees´ performance present similar steps in both investigated contexts. However, the physical SBT protocols are paper based while the virtual SBT one´s are done through the computer platform. The computer platform permits an automatic record of simulation data, including a timeline containing each operator's commands, providing easy information recovery and filtering, making debriefing easier. Also, it permits the operator´s self-assessment in the platform, speeding up result analysis and comparison.

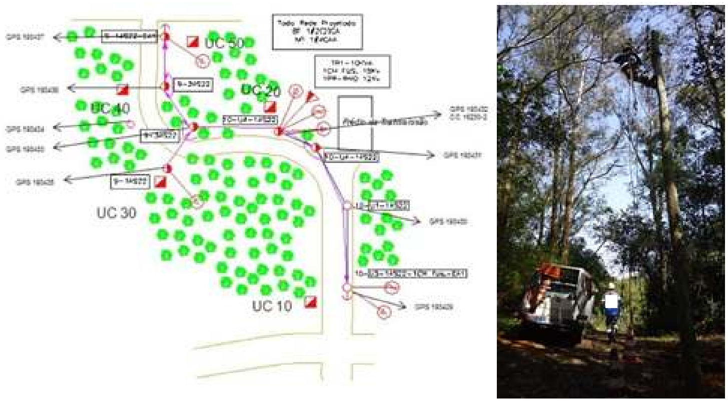

Fig. 1. On the left: map given to electricians in the briefing stage of SBT. On the right: view of the electricians during a simulation session

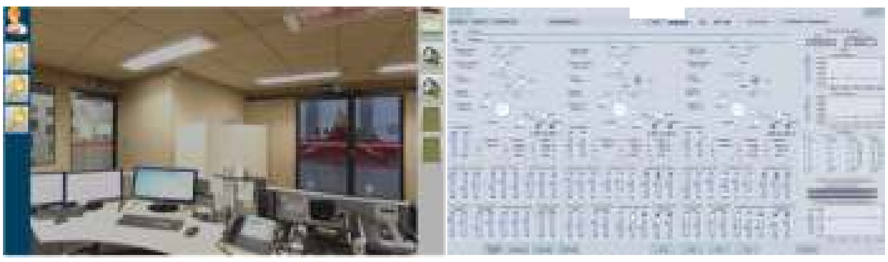

Fig. 2. On the left: control room virtual environment. On the right: example of a supervisory screen

4.4 Testing and refining the scenarios and the protocol

The testing phase of physical SBT was completed and the company has used the proposed method as part of their electricians´ formal training. On the other hand, the project involving virtual SBT is in the final stages, still undergoing testing. A total of 18 test simulations were conducted for the physical SBT, while only 3 were done in virtual SBT. In fact, the project related to the hydroelectric power plant was much more time-consuming in terms of data collection and development of the "simulator" (i.e. the computer platform, in this case). Therefore, there was relatively less time available for testing the simulator in practice.

5 COMPARISON BETWEEN THE TWO CONTEXTS

Developing and conducting SBT using different types of scenarios (physical or virtual) allows the strengths and weaknesses of each technology to be assessed, as shown in table 3.

Table 3. Comparison between the different simulation technologies

Criteria	Physical Scenario	Virtual Scenario
Space	substantial need for physical space, since a full scale network was built	reduced need for physical space, involving just a room for locating the computers and servers (Figure 3)
Physical resources for setting up the simulation	low voltage grid with five consuming units and transformer and equipped truck	simulation room with the computers and communication radios
Time for building the scenarios	less time-consuming for building the network (low voltage grid) – one year	more time-consuming for developing the computer platform three year
Realism of the scenarios	more realistic environmental conditions (e.g. vegetation, lighting, ...)	use of media from the actual environment to ensure greater realism and use of technology to simulate environmental conditions (e.g. night, rain) However, the use of media restricts some realism since a photograph is a static image

Control over work constraints introduced in the simulation	less control over work constraints, although this can be beneficial for RS training, since unexpected scenarios can be created involuntarily	greater control over work constraints
Record of simulation data	manual record of data gathered by the instructor	automatic record of simulation data, including a timeline containing each operator's orders, providing easy information recovery and filtering, making debriefing easier
Assessment	on paper, requiring manual result analysis and comparison	in the platform, speeding up result analysis and comparison

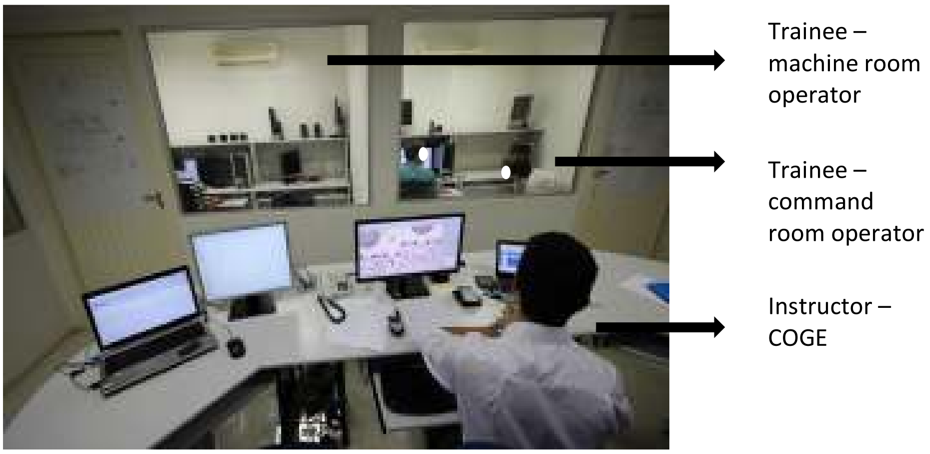

Fig. 3. View of the virtual simulation room and participants

6 CONCLUSIONS

The focus of this study was to present a new application of a SBT method for RS training and compare two types of technologies for SBT, one using physical simulations and the other applying virtual ones.

The strengths and weaknesses of the simulation technologies may be more related to the context in which each was applied, rather than to the technologies themselves. For example, in the hydroelectric power plant, physical simulation is difficult due to economic and environmental reasons, making simulation using a computer platform a viable alternative. In this case, where the plant is controlled remotely via a computerized operating system, simulation using a computer platform is very similar to the actual work environment.

The results also indicated that the adopted method for SBT is in line with the four basic abilities of resilient organizations described by Hollnagel et al. (2011): responding, monitoring, anticipating and learning. Indeed, the RSs identified in both contexts may be associated with those four abilities. In particular, the ability to learn is developed in the debriefing phase. As such, regardless of the context and simulation technology, this ability can be practiced in the debriefing.

Another important point is to reflect on system redesign suggestions, which can provide organizational support for worker resilience. None of the companies involved in this research committed to or showed interest in applying the phase involving system redesign. This is an important gap from a resilience engineering standpoint, which may indicate how unprepared companies are for this philosophy, focusing on individuals as opposed to the system as a joint cognitive system.

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Appendix 1. Resilience skills and constraints for electricians and hydroelectric power plant operators (light gray signs means similar RSs)

	Electricians (Wachs et al, 2012)	**Hydroelectric Power Plant Operators**
Resilience Skills	To discuss, with the central operations control room team, procedures to be followed and/or to request information on the network	To coordinate activities with the COGE
	To discuss, with the colleagues who are in the field, to build a shared understanding on the situation	To coordinate activities with the other shift worker
	To discuss, with the consumers and population, the status and hazards of the power line maintenance procedures, as well as the possible causes of defects	
	To express doubts and fears to other team members and request help from them	
		To coordinate activities with maintenance staff
		To coordinate activities with other actors
	To identify structures, lines or equipment that are non-standard, damaged or have failed	
	To identify visible signs in the environment that indicate difficulties in doing the task or the likely causes of damages to the line	
	To draw up strategies to identify defects in the power line	To interpret information from supervisory controllers, equipment or the environment
	To draw up work strategies, after the defects have been identified	To draw up action strategy to reestablish plant operations
	To plan and to check the availability of the equipment and materials that are necessary to undertake the task	
	To distribute the task between team members and to do the task accordingly	
	To identify sources of stress and fatigue	To identify sources of stress and fatigue

	To draw up strategies to cope with stress and fatigue	
		To determine priority actions
		To understand the role of each piece of equipment in the plant’s operations
		To recognize the power plant as an interconnected generation system
		To recognize the implications of stopping the generation unit
Constraints	Activity carried out previously, at the same location, in an inadequate way	
	Lack of equipment or materials to undertake the activity	
	Failure in power line equipment or materials	Equipment failure or damage
		Failure of the supervisory control system
	Lifting weights and need to use a lot of physical strength	
	Long working hours	Increased operational workload
		Increased bureaucratic workload
	Lack of support from a colleague	
	Pressure from supervisors, central operations control room or clients	Time pressure
	Problems at the interface between the electricians in the field and the operations center	
	Difficulty of access to the region	
	Difficulty of access to the power line	
	Night	
	Adverse weather conditions	Problems outside the power plant
	Region in turmoil because of urban violence	
	Presence of animals or insects	

actions for redesigning the socio-technical system	Acquiring equipment with greater range to facilitate communication between electricians at the field and among them and the central operations control room	Providing the equipment needed for power plant activities
	Updating the company's maps, especially in terms of street names and characteristics of the network	Implementing a management system for information collected by the ODR (operator driven reliability)
	Providing mobile devices to support lanterns required for night work	Implementing a training and continuous education program for operators
	Re-evaluating and possibly increasing the number of operators in the central operations control room	Developing procedures to ensure operating staff are aware of all the activities performed at the plant
	Training teams to read and interpret maps	Optimizing signals/alarms used in the supervisory control system
	Performing cross-training events between teams of electricians and from central operations control room, so that one party gets to know the reality of the work of the other party better	Carrying our corrective maintenance on equipment
	Expand preventive maintenance actions in the network	Reducing the workload of operators
	Develop standards for communication between field teams and central operations control room	
	Broaden and strengthen the practice of filling a checklist of available materials and tools at the beginning of each shift	
	Improve the distribution of tasks among the different shifts so as to reduce overtime	
	Draw up a formal program for refusing risky tasks	
	Increasing the frequency of inspections to identify constructions next to the power lines, thus detecting situations in which the minimum distances between the lines and buildings is not respected	

	Increasing the frequency of inspections in areas known to have many clandestine connections	
	Conducting public awareness campaigns about the dangers of the power lines and about the dangers of clandestine connections	
	Defining together with other institutions which share the grid (for example, town hall and the secretary for the environment), procedures of use and maintenance	