2007 International Nuclear Atlantic Conference - INAC 2007
Santos, SP, Brazil, September 30 to October 5, 2007
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
ISBN: 978-85-99141-02-1

HUMAN RELIABILITY ANALYSIS AS AN EVALUATION TOOL OF THE EMERGENCY EVACUATION PROCESS ON INDUSTRIAL INSTALLATION

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ABSTRACT

Human reliability is the probability that a person correctly performs some required activity by the system in a required time period and performs no extraneous activity that can degrade the system. Human reliability analysis (HRA) is the analysis, prediction and evaluation of work-oriented human performance using some indices as human error likelihood and probability of task accomplishment. The human error concept must not have connotation of guilt and punishment, having to be treated as a natural consequence, that emerges due to the not continuity between the human capacity and the system demand. The majority of the human error is a consequence of the work situation and not of the responsibility lack of the worker. The anticipation and the control of potentially adverse impacts of human action or interactions between the humans and the system are integral parts of the process safety, where the factors that influence the human performance must be recognized and managed. The aim of this paper is to propose a methodology to evaluate the emergency evacuation process on industrial installations including SLIM-MAUD, a HRA first-generation method, and using virtual reality and simulation software to build and to simulate the chosen emergency scenes.

1. INTRODUCTION

Human error is any member of a set of human actions that exceed some limit of acceptability. It is an out-of-tolerance action, where the limits of acceptable performance are defined by the system [1]. Human reliability is the analysis, prediction and evaluation of work-oriented human performance in quantitative terms using some indices as human error likelihood and probability of task accomplishment. HRA has three basic functions, namely the identification of human errors, the prediction of their likelihood and reduction of their likelihood, if required [2]. Human reliability can be useful in diagnosing the factors that lead to less than desired human performance and can also be used to determine the increase in performance. Quantitative HRA can be used in probabilistic risk assessments (PRA), where the resulting probabilities of failure for task sequence are combined with probabilities of failure for the equipment in a system fault tree or a system event tree. Human reliability considerations occupy an important place in the engineering of complex systems. During the last decade it has become self-evidence that to minimize the probability of failures, the human factor must be taken into account. The dependability of people to make the correct decision and then take the correct action at the correct time cannot be overlooked. The purpose of HRA is to render a complete description of the human contribution to risk and to identify ways to reduce the risk.

HRA has its roots in the study of human performance. The assessment of the human error becomes a tool for identifying the factors that influence the human performance. These factors are known by risk analysts as performance shaping factors (PSFs). PSFs include the quality of the operations, inservice tests, procedures, the quality of the interfaces, training, workload, stress, environment, etc [3]. When these factors adversely affect performance of a given task, there is opportunity for improving performance by making the PSFs more favorable. Human performance is also influenced by whether personnel have to rely on intuition, past experience, personal knowledge versus well-defined knowledge.

The major need in HRA is for quality data. Data from data base is available [1]. If properly collected, data from experiments in simulators, from plant operations are very useful. The general objective of HRA methods is to produce numerical data for use in probabilistic risk assessment (PRA), bring about improvements in plant safety and improvements in plant performance and availability. Some HRA methods are used in the quantification of probability of failures for the human actions, such as THERP (technique for human error rate prediction), SLIM-MAUD (success likelihood index method multiattribute utility decomposition), HEART (Human error assessment and reduction technique) and HCR (human cognitive reliability).

The aim of this paper is to propose a methodology to evaluate the human performance during the emergency evacuation process of the workers on industrial installations. This methodology includes a HRA first-generation method, SLIM-MAUD, and computational tools, such as virtual reality and simulation software, to build and to simulate the chosen emergency scenes.

2. THE SLIM-MAUD METHOD (SUCCESS LIKELIHOOD INDEX METHOD MULTIATTRIBUTE UTILITY DECOMPOSITION)

The study of the human factors is a scientific discipline that involves the systematic application of information relating to human characteristics and behavior to enhance the performance of man-machine systems. The initial of studies about human error prediction has come from the nuclear industry through the development of expert judgment techniques such as SLIM-MAUD. The need for expert judgment techniques lies in the lack of human error data. The SLIM-MUD technique is intended to be applied to tasks at any level of detail and its development was prompted by lack of HEP (human error probability) data. Errors can be quantified at various stage including tasks and sub-tasks. The premise of SLIM-MAUD is that the probability of a human error associated with the task is a function of the PSFs associated with the task. It assumes that experts can rate the PSFS and estimate the failure rates. The SLIM uses ratings of the relative goodness of PSFs in a particular situation weighed by their relative impact as determined by a panel of experts. The analysts provide values employed as upper and lower bounds on failures rates for a particular task. The method assumes that the log of success probability is equal to the experts judgment and two empirically derived constants. Two tasks for which the probability of success are known are required, and in order to estimate a HEP, success probabilities must be subtracted from 1.0.

Variants of the core SLIM procedure lie in the treatment of the rating and weighting data, and how the elicitation of those data is performed. An extension of SLIM presents the use of multi-attribute utility decomposition (SLIM-MAUD). Multi-attribute decision problems are decision making situations in which the alternatives are described by their attributes (PSFs) that cannot be optimized simultaneously. This technique provides a method for quantifying how important each PSF is in comparison to the other PSFs [3].

3. THE COMPUTATIONAL TOOLS

Some computational tools will be used, such as s virtual reality and simulation software, to build and to simulate the chosen emergency scenes.

3.1 Virtual Reality

CAD software have been developed for design of machines, systems, workplaces, etc, utilizing design parameters derived from a real model of the product, such as, shape, size, distance and position. 3D visualization technology was originally developed for viewing and design CAD files. It uses 3D polygons so that the file size becomes small enough for its transmission and manipulation. Although this simplification process discards some high level design features, important geometric data are retained. It demonstrates the potential of 3D visualization as an interface technology for human factors evaluation. Virtual prototype is a simulation of an object with an adequate degree of realism that is comparable with the physical functionality and the appearance of the real object [4]. Virtual design is a process applied to the development of a product that uses virtual prototypes in selected process phases. Typical simulated features are includes, such as visual appearance, shape, texture, surface materials, colors, displays, lights and mechanical controls. Stereo vision is often included in a virtual reality system. This is accomplished by creating two different images of the world, one for each eye. The images are offset by the equivalent distance between the eyes. The images can be projected through differently polarized filters, with corresponding filters placed in front of the eyes and displayed sequentially on a conventional monitor or on projection display.

3.2 Simulation Software

Simulex: It is a software tool capable of modeling the evacuation of large populations through multi-storey buildings and the physical presence of each person as the person moves through complex spaces. It produces more comprehensive analysis of emergency evacuation times and highlights potential problem areas of the evacuation strategy. Human movement parameters such as rates of body twist, acceleration/deceleration and speed have all been collated during extensive tests. The tests demonstrated that Simulex accurately models individual movement, and hence produces realistic results when the performance of group is analyzed. The output of the model tracks the individual position throughout the evacuation. Also, the occupants have an individual view of the building because the route choice can consist of either the shortest route calculated by the default distance map or a user-defined route obtained by assigning an alternate distance map to an individual or group of occupants.

Exodus: The purpose of this model is to simulate the evacuation of a large number of person from a variety of enclosures. The model consists of six sub-models that interact with one another to pass information about the evacuation simulation. They are the Occupant, Movement, Behavior, Toxicity, Hazard and Geometry sub-models. The model views the occupants as individuals by giving each occupant certain characteristics. The occupant sub-model's purpose is to describe information such as gender, age, maximum running speed, maximum walking speed, response time, agility, patience, drive, etc. The sub-model also maintains such information as the distance traveled by the occupant throughout the simulation, the person's locations, and exposure to toxic gases. Some of these attributes are static, and some of these change with the conditions in the building.

Egress: The purpose of this model is to determine the evacuation of crowds in a variety of situations, such as theaters, office buildings, railway stations, and ships. The floor plan of a building is covered in cells that are equivalent in size to the minimum area occupied by an occupant. Instead of being square, like most grid cells, the cell is hexagonal in shape. The model views the occupants as individuals. The movements of each occupant are carefully monitored throughout the simulation. Each individual also has certain goals and a specified time period to complete that goal. The occupants' perspective of the floor plan is also individual. EGRESS contains a route finding algorithm that defines the shortest distance from each cell on the floor plan to each specified region or exit. Then, the behavioral modeling aids in choosing which objective the occupants moves toward.

Simwalk: It is a multi-purpose pedestrian simulator that allows to evaluate and to ensure the security and comfort of walking in different environments. It models every pedestrian - up to thousands of pedestrians - as single persons with their behavior and goals. Typical applications of Simwalk are: security testing of egress routes of complex buildings, design and walk-ability validation of public buildings and integration of pedestrian scenarios in normal traffic simulation.

The figure 1 shows a simulation of an emergency scene using a computational tool.

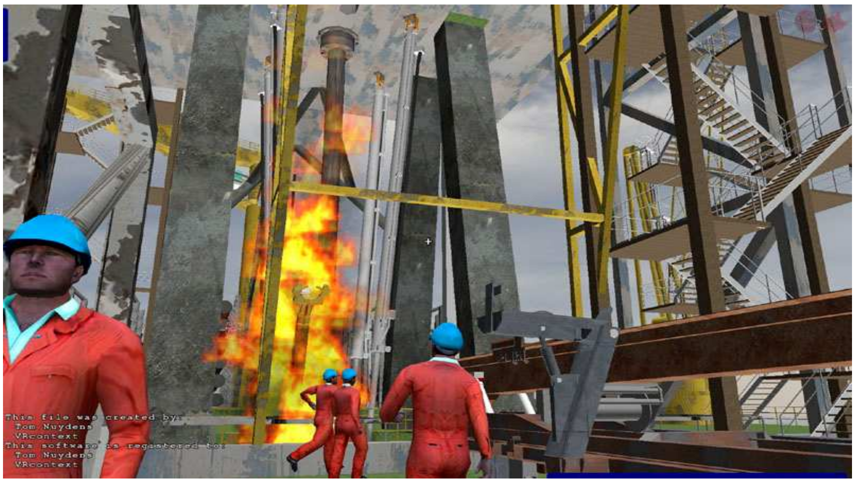

Figure 1: The simulation of an emergency scene

4. THE EMERGENCY EVACUATION PROCESS

A key element of emergency planning is the evacuation planning. Protective action recommendations (PAR) are recommendations made to decision makers in an emergency. These recommendations generally involve three choices for workers action: do nothing, shelter in place, or evacuate the area. The mobilization time represents the time required by evacuees to perform all their necessary preparatory activities prior to starting the trip. Good evacuation planning methodology involves an iterative process to identify the best evacuation routes and to estimate the time required to evacuate the area at risk [5].

An industrial installation presents many risks in the form of process hazards, gas release, radiation, fire and explosion. These events can occur at any time. The evacuation alarm indicates to all personnel to start the evacuation sequence and gather at the temporary safe refuge. The workers are required to stop the work and to return the process to a safe state. The next step is to make their workplace safe so that the others workers will not be impeded by obstructions. Once the temporary safe refuge is reached, all workers are required to register their name on a tag. After, the tags and workers count are performed and all personnel are required to remain in the temporary safe refuge. The key aspects to a successful evacuation are influenced by the type of the human error and the severity of the event initiator. The factors that define a successful evacuation are: early recognition, accurate evaluation, quick access to egress route and efficient travel to temporary safe refuge [6]. The emergency evacuation process concerns with the actions beginning at the time of event initiation (Ti) and ending with the tasks performed in the temporary safe refuge (TSR), before moving on to the abandonment phase. Each phase of the evacuation process has an associated elapsed time, such as Ta, Tev, Teg and Tr. These times make up the total time of evacuation (Tevac).

$$Tevac = Ta + Tev + Teg + Tr$$

The figure 2 shows the graphical representation of the phases of the evacuation sequence. The first three phases (awareness, evaluation and egress) are the phases where workers have the greatest exposure to the effects of the initiator event (e.g. heat, smoke, pressure) and to high levels of physiological and psychological stress.

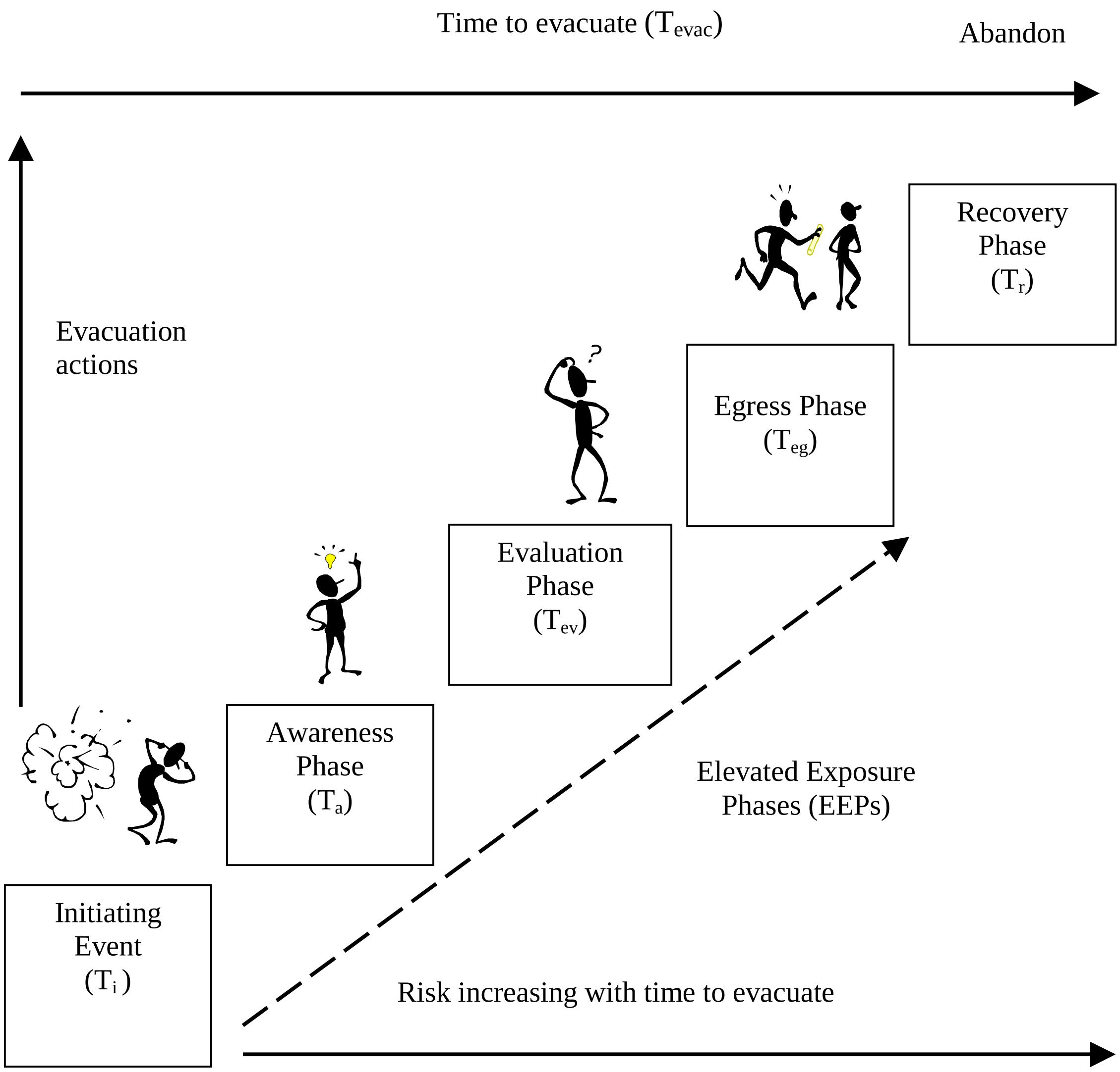

Figure 2. Graphical Representation of the Phases of a Evacuation Sequence (Adapted from Dimattia [7])

5. THE METHODOLOGICAL FRAMEWORK

The proposed methodological framework to evaluate the human reliability during the emergency evacuation process on industrial installation, is shown in figure 2. The phases are:

- Phase 1: Establish criteria to choose and to rank the following judges: the principal team (PT) and the elicitation team (ET).

- Phase 2: The PT defines the emergency evacuation scenarios.

- Phase 3: The PT develops the hierarchical task analysis for each evacuation scenario.

- Phase 4: The PT develops a list of the most relevant PSFs through a pairwise comparison.

- Phase 5: The PT develops the questionnaire for determining the PSFs weights and ratings.

- Phase 6: The ET determines the importance weights for each of the PSFs.

- Phase 7: The ET rates each action on the hierarchical task analysis through a numerical scale.

- Phase 8: Perform statistical checks on the data from phase 6 and 7.

- Phase 9: Determination of human error probabilities through the SLIM-MAUD procedure.

- Phase 10: Develop the risk consequence and risk mitigation for each muster scenario

The phases 6 and 7 are supported by the following resources: administrative and operating procedures, video tapes of emergency training, analysis of workers performance during emergency training, simulation using computational tools, such as virtual reality, simulex, exodus, simwalk or egress software. Through these aid tools, the elicitation team (ET) can get useful information and data that will help them to determine the importance weights for each of the chosen PSF and to assign a value on the numerical scale.

4. CONCLUSIONS

In this paper we have presented a methodological framework to analyze the human reliability during the emergency evacuation process of the workers of an industrial installation. Due to a lack of human error databases for the emergency evacuation of the industrial installation, an expert judgment technique, the SLIM-MAUD, will be used to predict human error probabilities. The chosen of the simulated scenarios is based on the expert judgment, on the expert experience, on the analysis of evacuation procedures, and on the observations of the evacuations drills. The elicitation team (ET) determines the importance weights for each of the PSFs and rates each action on the hierarchical task analysis. Computational tools may be used by ET as an aid support to the elicitation of these data. The computational tools, such as virtual reality, simwalk, exodus and simulex, can be used to build and to simulate the chosen scenarios. The data taken from the simulations may be used by the experts to improve the elicitation of more PSF data.

The results of this research may be used in the identification of the areas where traditional evacuation training does not adequately prepare workers to deal with high stress and difficult environments. The results will provide a clear indication of situations where the risk is highest, which actions can end in failure, which PSFs affects the performance of the workers and increases the times related to awareness, evaluation, egress and recovery phases.

REFERENCES

1. Swain, A. D. and H. E. Guttmann, H.E. *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant applications*, NUREG/CR-1278, U. S. Nuclear Regulatory Commission (1983).

2. Reason, J. *Human Error*. Cambridge, University Press (1990).

3. Embrey, D. E., Humphreys, P. C., Rosa, E. A., Kirwan, B. and Rea, K. *SLIM-MAUD: an Approach to Assessing Human Error Probabilities Using Structured Expert Judgment. Report No. NUREG/CR-3518 (BNL-NUREG-51716)*. Department of Nuclear Energy, Brookhaven National Laboratory, Upton, NY (1984).

4. Stanney, K. M. *Handbook of Virtual Environments: Design, Implementation, and Applications*. Human Factors and Ergonomics, February 1 (2002).

5. Bellamy, L. J. *The Influence of Human Factors Science on Safety in the Offshore Industry.* Journal of Loss Prevention in the Process Industries, 7(4), 370-375 (1994).

6. Lorenzo, D. K. *A Guide to Reducing Human Errors, Improving Human Performance in the Chemical Industry.* The Chemical Manufacturers' Association, Inc., Washington, DC, (1990).

7. DiMattia, D.G. *Human error probability index for offshore platform musters*. Ph.D. Thesis, Department of Chemical Engineering, Dalhousie University, Halifax, NS, Canada (2004).