U.P.B. Sci. Bull., Series C, Vol. 74, Iss. 2, 2012 ISSN 1454-234x

THE MAN-MACHINE-ORGANIZATION SYSTEM ANALYSIS IN ACCIDENT CONDITIONS FOR NUCLEAR INSTALLATIONS

Mita FARCASIU[1], Ilie PRISECARU[2]

În această lucrare a fost dezvoltat un nou model de analiză a sistemului om-maşină-organizare astfel încât sa fie posibilă identificarea şi evaluarea problemelor reale care ar putea conduce la erori umane în secvenţele de accident. Alt scop propus este dezvoltarea unui cadru de lucru predefinit pentru a investiga cauzele de bază ale accidentelor. Rezultatele obţinute în această lucrare sunt recomandate a fi utilizate în proiectare, planificare (mentenanţă, testări, etc.) şi studii de evaluare probabilistă a securităţii pentru instalaţiile nucleare.

In this paper, a new man-machine-organization system analysis model was developed. The main objective of this model is to perform the identifying and the evaluation of the real problems which could lead to human errors in the accident sequences. Other proposed purpose is the developing of a pre-designed framework to investigate the root causes of the accidents. The results of this paper are advised to be used in design, scheduling (maintenance, tests, i.e.) and probabilistic safety assessment studies for nuclear installations.

Keywords: human, machine, organization, accident, nuclear

1. Introduction

In the last years, the industry domain (chemical, air, nuclear, i.e.) was marked by events which were attributed the human errors. Failures in human actions, in organization or in the management of nuclear installations contribute to 48% of events reported in the IAEA/NEA Incident Reporting System (IRS) **[1]**. Few events due to only technical causes or new phenomena which led to unexpected behaviour of NPP occurred.

The operating experience of the complex systems demonstrates that the man is only a component of the **M**an-**M**achine-**O**rganization **S**ystem (**MMOS**). The errors cannot be evaluated individual. A general conclusion of the achieved studies on the occurred incident or accident can be so and so formulated: "nuclear facility represents a combination between systems and humans in an organized

[1] PhD student, Scientific Researcher. Institute for Nuclear Research, Pitesti, at University POLITEHNICA of Bucharest, Romania, e-mail: mita.farcasiu@nuclear.ro

[2] Prof., PhD Advise, Power Engineering Faculty, University POLITEHNICA of Bucharest, Romania

manner". In [2] is specified that: "we can't change the human condition but we can change the conditions under which people work". Also in [3] is specified that "it is necessary to try to change the situations, not the human". All these arguments determine many researchers direct one's attention to the human and organization factors research.

Although, many methods were developed to evaluate the human and organizational factors, the human error appears yet and the human and organizational factors research is an actual research field.

The estimation of the contribution of the human factor and organizational to the complex system operation is a difficult process. This difficult appears both by the installation complexity and by the human complexity.

In this paper a new **MMOS A**nalysis (**MMOSA**) model was developed so that to be possible the identification and the evaluation of the problems which could lead to human errors in the accident sequences. The developing of a pre-designed framework to investigate the root causes of the accidents is another purpose proposed. The results of this analysis are used in design or/and **P**robabilistic **S**afety **A**ssessment (**PSA**) study. The model is developed using the studies of the individual capabilities and characteristics of the man, the machine and the organization in the man-machine-organization relationship. Also the **H**uman **R**eliability **A**nalysis (**HRA**) techniques and methods (THERP, SPAR-H), the scientific literature and the conclusions of the studies on the happened accident (Three Mile Island, Chernobyl, Bhopal,) are used. The results of this paper are the interfaces of MMOS and their circumstances, the multiple factors estimation of the negative and positive influences on the human error probabilities to be incorporated in PSA study.

2. The Man Machine Organization System (MMOS)

The studies of the major accidents from nuclear installation denote the fact that rare this result from chance failures of the equipments, but for the most part result from a combination between human and the organizational errors and equipments failure. In the last years it have been agreed that many technical issues from nuclear field were resolved but the issues of the human and organizational factors are yet in the identification, study and research phase.

To ensure safety of nuclear power plant operation it is necessary to address the issues associated with human performance within socio-technical system in which human factor is embedded [4].

Thus the need to study and model MMOS appears as obvious. The essential elements of MMOS are shown in figure 1.

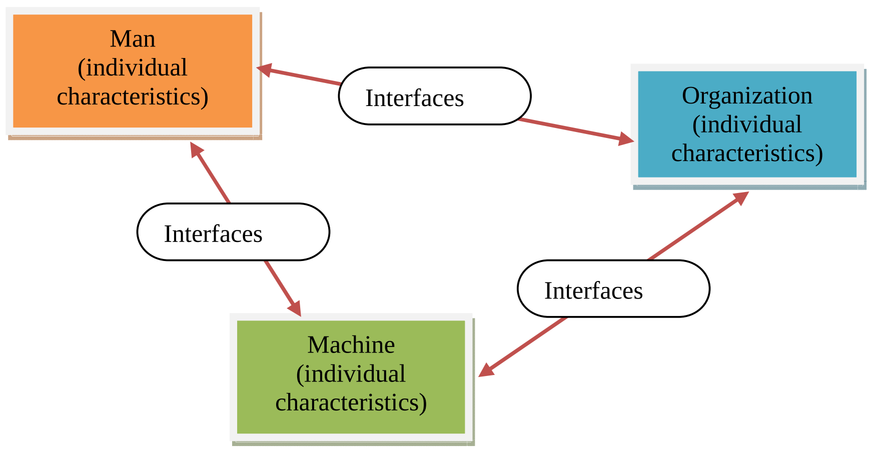

Fig. 1 – MMOS and the relations between its elements

There are: the man, the machine and the organization. In this paper they are defined as:

- the ***man*** is an employee in any position of an organization with a clear role and a responsibility well defined. The individual characteristics of the human are the anthropometrical particularities, the psychic state, the professional education and the aptitude. In [5] the human behaviour represents what a human does and says. It is a noticeable act which can be seen and heard. It is measurable
- the ***machine*** represents the instrument by a function or a process carried out in a complex system. The individual characteristics of the machine are: the constructive elements (components, systems and structures), the technical and economical parameters and the reliability).
- the ***organization*** is a function of a people group who have a clear mission, resource and planes to turn the human behaviour toward a sure and reliable operation. The individual characteristics of the organization are the communication, the make-decision, the standardization and the culture.

3. The Man Machine Organization System Analysis (MMOSA) model

The MMOSA model is developed to analyse qualitative and quantitative the human performance in the MMOS context for the accident conditions. The qualitative analysis model developed in this paper evaluates the interfaces between the organization and man, organization and machine and machine and man in the contextual medium of the event. The man-organization, the organization-machine and the machine-man interfaces accomplish the function which assures the safety and reliability of MMOS.

For each interface, the circumstances which can be at the given moment are identified. The circumstance of an interface represents a condition at the given moment and context.

The quantitative analysis model of the human performance in the MMOS context developed in this paper uses both HRA techniques and methods and new techniques. This model contents the following phases:

(1) The investigation process of the human actions (documentation, procedure interviews, i.e.);

(2) The appraisal of the possible human errors (human interaction types and human errors types);

According to [6] the human interactions are classified in five types to understand how human interactions are treated in PSA studies:

- Type 1 – before an initiating event (activities during testing, maintenance)
- Type 2 – by committing some error, plant personnel can initiate an accident
- Type 3 – by following procedures during the course of an accident, plant personnel can operate standby equipment that will terminate the accident
- Type 4 – plant personnel, attempting to follow procedures, can make a mistake that aggravates the situation or fails to terminate the accident
- Type 5 – by improvising, plant personnel can restore and operate initially unavailable equipment to terminate an accident

The categories of incorrect human outputs related to human reliability analysis are the following [7]:

(a) omission errors :
  - omits entire task
  - omits a step in a task

(b) commission errors
  - selection error
  - error of sequence
  - time error (too early, too late)
  - qualitative error (too little, too much)

(3) The estimation of **B**asic **H**uman **E**rror **P**robabilities (**BHEP**) from generic or/and specific data base;

(4) The determination of the dependence level between actions using a

positive dependence model in which five dependence levels are evaluated as distinct points situated on continuously spectrum of the positive dependence. The estimation of **C**onditional **H**uman **E**rror **P**robability (**CHEP**) is performed using the equations from table 1 from [7] in according to the established dependence level.

Table 1

A positive dependence model

Level of dependence	**Equations**	**No. Eq.**
ZD (zero dependence)	$CHEP = BHEP$	(1)
LD (low dependence)	$CHEP = \frac{1+19BHEP}{20}$	(2)
MD (moderate dependence)	$CHEP = \frac{1+6BHEP}{7}$	(3)
HD (high dependence)	$CHEP = \frac{1+BHEP}{2}$	(4)
CD (complete dependence)	$CHEP = 1$	(5)

(5) The comprehension of the action in MMOS to identify of the MMOS interfaces using our qualitative analysis model:

- Man-machine interfaces;
- Machine-organization interfaces;
- Man-organization interfaces.

The positive or negative conditions which can influence the human action at the analysis moment are identified for each interface.

(6) In this paper was developed a quantitative analysis technique of the influences of the negative or positive conditions using the limits of human error probabilities according to [7]:

- BHEP = 0.1 (pessimist situation)
- BHEP = 0.0001 (optimistic situation)

In order to develop this technique the following situations were considered:

(I) In order to the pessimist situation where BHEP = 0.1 and CHEP = 0.55 for high dependence level supposed that all conditions have a negative influence. Then:

$$HEP = CHEP * k_1^{\,i} \qquad (6)$$

Where:

k_1 is the multiplication factor of CHEP for each condition with negative influence

i is the number of the conditions with negative influence

The maxim value of the **H**uman **E**rror **P**robability (**HEP**) is equal with 1. Then:

$1 = 0.55 * k_1^i$

$$k_1^i = \frac{1}{0.55} \quad (7)$$

(II) In order to estimate the multiplication factor for positive influence conditions take into account:

$$\text{CHEP (optimistic)} = \text{CHEP (pessimist)} * k_2^j \quad (8)$$

Where:

k_2 is the multiplication factor of CHEP for each condition with positive influence

j is the number of the conditions with positive influence

To optimistic situation where BHEP = 0.0001 and CHEP for zero dependence = 0.0001 take into account that all conditions have a positive influence. Then:

$0.0001 = 0.55 * k_2^j$

$$k_2^j = \frac{0.0001}{0.55} \quad (9)$$

(7) The human error probability estimation

$$HEP = CHEP * k_1^i * k_2^j \quad (10)$$

Where:

i is the number of the negative conditions

j is the number of the positive conditions

Note: If CHEP = 1 then the analysis is not performed.

(8) The documentation is a final phase. It is a report which will contain all elements considered to analysis and all results to be incorporated both in PSA study and design process.

4. Results

The study on the individual capabilities and characteristics for human, machine and organization and interdependence analysis between them has identified the interfaces and their circumstances. The dependence between machine and organization, man and organization and man and machine is given by elements which represent interfaces MMOS so that to be satisfied the needs of the machine, man and organization performance in the facility operation. Based on papers [8], [9], [10], [11], [12] and own consideration a qualitative MMOS analysis model was performed. The interfaces and their conditions in the man-machine system regard to the equipment types on the human acts and the dependence level between action and the previous action (table 2).

Table 2

Interfaces and their conditions in Man-Machine System

Interfaces	**Conditions**
Equipment	Annunciated display
	Button switch
	Unannunciated display Manual control
	Manual valve Microcircuit
	Pump
	Tank
The dependence between two actions	Low
	Moderate
	High Complete
	Zero

The dependence between machine and organization is given by elements which represent interfaces of the machine-organization system so that to be satisfied the needs of the machine performance in the facility operation.

Each interface is characterized by circumstance which could fail the machine performance and lead to accidents. The circumstance of an interface represents a condition at the given moment and context. The interfaces of this system and their conditions are presented in table 3.

The dependence between man and organization is given by elements which represent interfaces of the man-organization system so that to be satisfied the needs of the human performance in the facility operation. Each interface is characterized by circumstance which could fail the human performance and lead to accidents. The circumstance of an interface represents a condition at the given moment and context. The interfaces of this system and their conditions are presented in table 4.

Table 3

Interfaces and their conditions in Machine -Organization System

Interfaces	**Conditions**
Maintenance plan	The program isn't based on risk study
	The maintenance department isn't well structured and organized It is not a continuum monitor of the equipments
	The program is not revised
	It is not an record of the maintenance actions They are not kept the maintenance records
	It is not a prioritization of the maintenance actions They are not adequate instruments for maintenance
	They are not estimated adequately the maintenance time periods
	It is not knew the degradation process It is not a maintenance evaluation program
	They are not performed post/maintenance tests
	They are not checked post/maintenance tests They are not performed suitable tests after modifications
Aging management plan	The aging susceptible components are not identified Monitoring methods of the aging process aren't introduced
	The corrective actions are not performed for limits or mitigate aging effects
Modification plan	It is not a plan for modification
	They are not performed suitable tests after modifications Modification analysis is not performed (safety and risk assessment)
Man-Machine Interface	Adequate
	Inadequate

Table 4

Interfaces and their conditions in Man-Organization System

Interfaces	**Conditions**
Training	Task not analyzed
	It is not decision for training
	The objectives is not learned The learning of the objective less than adequate
	The lesson plan less than adequate
	Instruction less than adequate The practice/repetition less adequate
	The testing less than adequate
	Training with simulator
Communication	Standard terminology not used
	Long message No method available
	Late communication
	Inadequate communication between departments Much communication required

Table 4

Interfaces and their conditions in Man-Organization System (continuation 1)

Interfaces	**Conditions**
The action complexity	Parallel task
	Multiple equipment unavailable
	Multiple faults High degree of memorization required
	System interdependencies not well defined Task requires coordination with ex-control room activities
	Symptoms of one fault mask other faults
	Transitioning between multiple procedures Misleading or absent indicators
	Large number of actions required
	Monitoring for > 3 elements in same time Interpretation requirements
	Permissible limits for small faults Distraction
Work environmental	Inadequate climate (temperature, noise, toxicity, vibration, lights)
Procedure	No procedure Not available for use
	Difficult for use
	Use not required but should be Confusing of the procedure
	> 1 action/step
	Excess references
	No check-off
	Data/computation wrong or incomplete Graphics less than adequate
	Details less than adequate
	Ambiguous instructions Limits less than adequate
	Typo
	Sequence wrong Incomplete situation not covered
	Dynamic
	Step-by-step
	It is written in other tongue than mother tongue
Time	Inadequate Close in time

Table 4

Interfaces and their conditions in Man-Organization System (continuation 2)

Interfaces	Conditions
Work process	Repeated actions
	Ambiguous roles, wants and responsibilities Ambiguous standards
	The loss of the standards
	Inadequate time for check The order of the actions in according to importance

Using the equation (7) for a maxim number of the negative influences (i = 74) resulted from qualitative analysis (the conditions from table 2, 3 and 4) then $k_1 \cong 1.008$. Using the equation (9) for a maxim number of the positive influences (j = 74) resulted from qualitative analysis then $k_2 \cong 0{,}9$.

If $k_1 = 1.008$ and $k_2 = 0.9$ then the equation (10) can be written so:

$$HEP = CHEP * 1.008^i * 0.9^j \tag{11}$$

In order to present the human performance evolution (for BHEP = 0.003) in different contexts (in according to influences), the charts "BHEP = 0.003 in MMOS context" (1) and (2) are performed (fig.2 and fig.3). The evolutions of HEPs are achieved both in negative conditions and positive conditions for zero, low, moderate and high dependence levels.

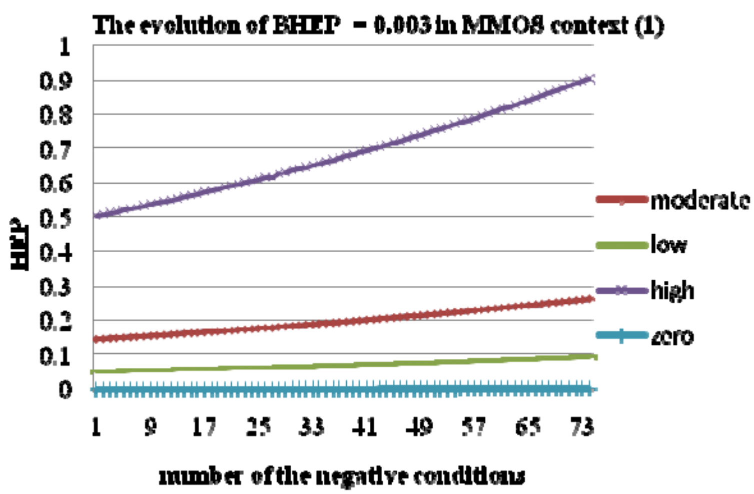

Fig. 2 - The evolution of HEP (for BHEP = 0.003) in the negative context of MMOS for different dependence levels

By the identification of the negative influence, the issues which lead to the events can be identified (corrective actions).

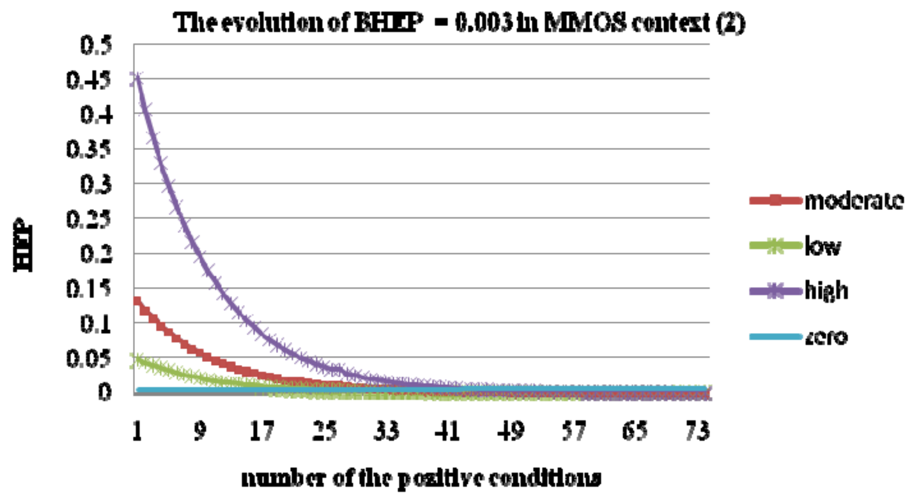

Fig. 3 - The evolution of HEP (for BHEP = 0.003) in the positive context of MMOS for different dependence levels

In these charts (fig. 2 and fig.3), the evolution and evaluation models of the influence degree of the interfaces on human performance for operation in accident conditions using MMOSA method are represented.

By the estimation of the positive influence the sensitive analysis of the MMOSA is performed to estimate the degree of the attenuation of the human error and the improvement of the human performance after the modification of the conditions.

5. Conclusions

MMOSA model is a framework which was developed to investigate the root causes which could be the causes of the accidents in nuclear installations. . Therefore, this model helps to identify the circumstances of the interfaces of MMOS in condition at the given moment and context. A large number of the interfaces (11) and their circumstances (74) suggest the complexity of this analysis type.

By evaluating the MMOS interfaces, the weakness in the designing of interrelationship between man, machine and organization which could lead to latent human errors may be identified.

The applicability of this model is ideal in real accident condition. It is difficult to be applied in hypothetical accident because the circumstances of the interfaces can vary from a context to other. Also the application of this model in the probabilistic safety assessment for the human reliability analysis and the identification of corrective actions are advised.

The evaluation and the optimization of the MMOS context allow the understanding and the improvement of the operation in the complex system. The results of this paper are advised to be used in design, scheduling (maintenance, tests, i.e.) and probabilistic safety assessment studies for nuclear installations.

But it is important to be remarked that decreasing of the amount of human responsibility in the operation of the plant leads to increasing of the amount of human responsibility in the design and organization of the plant.

R E F E R E N C E S

[1]. *OECD***.** Nuclear regulatory challenges related to human performance. 2004. ISBN 92-64-02089-6.

[2]. *Reason, James***.** Managing The Risks of Organizational Accidents. s.l. : Aldershot, 1997. UK: Ashgate.

[3]. *Kletz, T***.** A engineer's view of human error . New York : Taylor & Francis : (3rd ed.).

[4]. *Moray, Neville P. , Ed. and Huey, Beverly M., Ed.* Human Factors Research and Nuclear Safety. 1988. NRC-04-86-301.

[5]. *DOE***.** Human Performance Improvement Handbook. U.s Department of Energy Washington : s.n., 2009. DOE-HDBK-1028-2009.

[6]. *EPRI* Systematic Human Action Reliability Procedure (SHARP). s.l. : Proiect 2170, 1984. EPRI NP - 3583.

[7]. *A.D. Swain, H.E. Guttman.* Handbook of Human Reliability Analysis With Emphasis on Nuclear Power Plant Applications. Washington DC : U.S. Nuclear Regulatory Commission, August 1993. NUREG/CR -1278.

[8]. *NEA-CSNI***.** Better Nuclear Plant Maintenance:Improving Human and Organizational Performance . NEA/CSNI R(2008)12. ISBN 978-92-64-99065-4.

[9]. *IAEA***.** Best practices in Organization, Management and Conduct of an Efective Investigation of Events at Nuclear Power Plants . IAEA-TECDOC-1600.

[10]. *Martin, Schonbeck***.** Human and Organizational Factors in the Operational Phase of Safety Instrumented Systems a new approach. s.l. : Norwegian University of Science and Technology, 2007.

[11]. *NRC***.** Development of the NRC's Human Performance Investigation Process (HPIP). NUREG/CR-5455.

[12]. *D. Gertman, H. Bkackman.* The SPAR-H Human Reliability Analysis Method. Washington DC , 2005. NUREG/CR-6883.