Human error of commission modeled with Theory of Games

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***Abstract*— Industrial plants makes a carefully trace of the human intervention on the process. This intervention happens at different points in the history of the facility, since the design and building to the operation and maintenance. Error consequences in these activities where the human interacts with the plant can be potentially serious. Nevertheless, must be note that human intervention is beneficial for the plant performance optimization or in order to recover it of a fault.**

In this work we will focus on errors of commission. This type of error is made for a human who pretend to do a procedure in a different way to the pre-established form based on his/her experience.

In the international order exists a cup of methodologies that pretend to approach this subject but its application it is from extreme complexity for the most of the plants.

A new approach it is considered based on theory of games oriented to the understanding of the strengths and weaknesses of the organizational schemes of administration, control and supervision of operation and maintenance facility tasks.

***Index Terms*—Error of Commission, Human Reliability, Theory of Games.**

I. Introduction

Von Neumann and Morgenstern created the Theory of Games [1] in its classic book The Theory of Games Behavior published in 1944. Others were advancing some ideas. The economists Cournot and Edgeworth were particularly innovating in century XIX.

The mathematicians Borel and Zer did other later mentioned contributions. The same Von Neumann already had put the foundations in the article published in 1928.

Nevertheless, it was not until it appeared the book of Von Neumann and Morgenstern that the world understood how powerful was the discovered instrument to study the human relations.

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Von Neumann and Morgenstern investigated two approaches different from the Theory of Games. The first of them is the strategic or noncooperative approach.

This approach requires specifying in detail what the players can and they cannot make during the game and later look for each player an optimal strategy. What is better for a player depends on which the other players think to do, and this depends as well on which they think that the first player will do it.

Von Neumann and Morgenstern solved this problem in the particular case of games with two players whose interests are diametrically opposed. These games are called strictly competitive, or of sum zero, because any gain for a player always balances exactly by a corresponding loss for the other player.

The chess, backgammon and poker are games treated habitually like games of sum zero.

In the second part of the book, Von Neumann and Morgenstern developed the coalicional or cooperative approach, in which they looked for to describe the optimal conduct in games with many players. Since this one is a much more difficult problem, it is not to surprise that their results were much less precise that reached after the case of sum zero and two players. In individual, Von Neumann and Morgenstern left all attempts to specify optimal strategies for individual players. Instead of it they classified the models of formation of coalitions that are consistent with rational conducts. The negotiation, in this theory, did not play role. In fact, they did the point of view that had predominated between the economists at least from the time of Edgeworth, according to which the problems of negotiation between two people are inherently indeterminate.

To principle of the Fifties, in a series of articles very famous, the mathematician John Nash broke two of the barriers that Von Neumann and Morgenstern had themselves self-imposed.

In the noncooperative front, these seem to have thought that in strategies the idea of balance, introduced by Cournot in 1832, was not in itself an suitable notion to construct on her a theory - that's why they were restricted to games of sum zero - . Nevertheless, the general formulation of Nash of the balance idea made see clearly that a restriction thus is unnecessary.

The notion of balance of Nash, is not another thing that when the strategic election of each player is the optimal answer to the strategic elections of the other players.

The main objective of the theory of the games is to determine the rational conduct in situations of "game" in which the results are conditional to the actions of interdependent players. A game is any situation in which two or more players compete. The chess and the poker are good examples, but also they are duopolio and oligopolio in the businesses.

The extension whereupon a player reaches its objectives in a game depends on the chance, its physical and mental resources and those of its rivals, of the rules of the game and the courses of action that follow the individual players, that is to say, its strategies. A strategy is a specification of the action that is to undertake a player in each possible contingency of the game.

It is assumed that, in a game, all the players are rational, intelligent and well informed. In individual, it is assumed that each player knows all the existing strategies set, not only for him, but also for his rivals, and that each player knows the results of all possible combinations of the strategies.

Also, in a great variety of games, the result is a variety whose probability distribution must be established so that a solution for the game can be possible. In this respect, it must be noted that the decisions of the interdependent players have resulting payments of these decisions depending on the actions undertaken by all the players. This interdependence implies that it can be unsuitable to suppose that an invariant probabilistic process that is not affected by the course of action that one chooses is generating the payments.

In other words, the action that a player undertakes can dictate the acts of other players or influence in the probability that they behave in a particular form. This potentiality of possible effects in the results is the one that distinguishes the decision making in conflicts and the decision making in uncertain context.

The Theory of Games at the moment has many applications, being the economy the main client for the ideas produced by the specialists. Between the disciplines where there is application of the Theory of Games can be mentioned: political economy, sciences, biology and philosophy, among others.

In this work, an approach related to the denominated Error of Commission framed within which is known as Human Reliability Analysis and considers a new approach based on the Theory of Games.

This aproach is oriented to the understand the weaknesses and strengths of the organizational administration schemes, control and supervision of operation and maintenance facilities tasks.

The Human Reliability Analysis [2] in the researching of operations strictly began being a field of experts. But in 1983, Swain and Guttman develop THERP [3] (Technique Human Error Rate Prediction); a methodology focused in the calculation of the fault probability of making specific a procedure by means of an ordered set of actions.

In the same year SLIM appears (Success Likelihood Index Methodology). SLIM is a methodology based on the opinion of experts to define the fault rates in the concretion of a task. Both techniques continue at the moment being used and are excellent part of the set of techniques known like as of first generation.

In 1998 Hollnagel introduce CREAM [4] (Cognitive Reliability and Error Analysis Method). It is a taxonomy that compiles individual, technological and organizational factors based on principles of cognitive engineering.

In 2000 the Nuclear Regulatory Commission of the United States displays ATHEANA [5][6] (Technique Human Event Analysis) a methodology that incorporates the contexts like generating sources of error. Both techniques are known like techniques of second generation.

In 2006 the Nuclear Regulatory Commission of the United States published a document [7] where it can find a series of summary tables that highlight key characteristics of each methods as a quick reference. This document includes a series of summary observations, based on the information in the tables, which should help readers better understand similarities and differences among the methods, as well as current strengths and limitations of Human Reliability Analysis methods in general.

Actual theories have tendencies to model behaviour [8]. Years of specialized research on the issue on human error have indicated that the concept human error is far more complicated that originally assumed, to the point that come authors have recently proposed to reject the expression altogether.

Reference [8] argues that human errors are not fixed events that can be studied by mean of observation alone. Human error is instead a normative concept, which implies a process of comparing empirical events with abstract standards of correct performance.

Based on that this process and the standards are dependent upon the theories of human performance adopted, the application of the Theory of Games seems to be a good possibility.

A sub-set of the Human Reliability Analysis is errors of commission. These types of human error are very frequent in industrial activities and for that reason was selected as point of start. The study of the models able to foretell the probabilities of the personnel of an installation to commit errors of commission is an open subject internationally.

Although advances related to the modeling of errors of commission have been made a general consensus about the form of modeling and its quantification does not exist.

An important branch of the investigation centers its efforts in the study of the sociological and psychological components of the subject. Other branches focus their attention on the study of the consequences and the contexts (layout, type of procedures written, organization, etc.).

This last approach is the interest of this work.

II. Human errors types

The authors agree with A G Foord & W G Gulland [9] who argue that it would not be possible to design technological systems to eliminate all human errors during operation because people are involved in: specifying, designing, implementing, installing, commissioning and maintaining systems as well as operating them.

Thus to improve process safety it will be necessary to focus on behaviour and methods of working during all phases of the lifecycle so as to remove or reduce opportunities for human error.

Basically, human errors can be classified in two types of errors: errors by omission and errors of commission [10].

A. Errors by Omission

The errors default are those originated in the loss of a step (i.e. an instruction) within a sequence of steps for the accomplishment of a maintenance activity. The loss of this step can lead to deficient arming (e.g. is not placed in its place an element that prevents filtration, or that maintains assured a piece, etc.). Deficient arming, in an equipment standby can not be pronounced during the later test to the maintenance activity but that can even require a period relatively prolonged of operation or a series of periods of operation. The errors default, are not noticed by the personnel and they are not made to intention.

B. Errors of Commission

The errors of commission are born of a cognoscitive activity of the personnel. They can be originated by the necessity to gain time (e.g. before to finish a task to be able to initiate another one, to finalize the day of work, to fulfill the requirements of yield of the supervisor, etc.). The technician feels enabled to make decisions on the best form to make an activity. This confidence is born mainly of its experience with the equipment. An error of commission is a joint action or of actions that leave to an equipment with a latent fault, which can be showed when the action of the same one is required. The error of commission is not noticed by the personnel who makes it although he understands that he does not make the prescribed procedure.

The activity of supervision on a technician has among others the mission to limit the possibility of errors of commission, like only active measurement against those.

III. The facility and the organizational scheme

When the organizational scheme for the reliable administration of the tasks of maintenance of a facility is planned a necessity arises. It is the necessity to limit the possibility that the maintenance activities leave the equipment that normally remains standby in conditions such that do not allow their operation when they are required.

In the following it will see the necessary scene and actors for the interpretation and modeled of the error of commission.

A. The scene

The situation that is tried to model develops in a plant as a Nuclear Power Plant. This one was chosen to have statistical information related to the probability of human error in the concretion of diverse tasks. This will later allow to generate an analysis applied and to obtain conclusions that can be contrast with the present reality of the practices in these facilities.

B. The technician

It is assumed that the technical personnel is described and enabled according to the standards of the industry.

The main problem of the technician is to be able to complete the task that is entrusted to him in the time that is arranged to him.

Many activities of maintenance are made during plant operation, some of them can have time windows that could allow a more relaxed work. When being combined activities these times normally are limited.

Also activities exist whose time must be diminished (e.g. works in zones where the technicians can be put under diverse levels of radiation) and on the other hand appear a great set of maintenance activities that are grouped to be made in the periodic shutdowns of plant.

These last ones require a correct planning so that the technicians can make all the programmed tasks in the brief period of time that the plant will be outside production.

In this scene the technician is forced to make his task in the smaller possible time. This it is the trigger of a series of actions of the technician, where appear errors of commission that tend to optimize the time that demands the maintenance activity.

C. The supervisor

The supervisor is in a scene of permanent conflicts, generated by the lack of additional time.

Its mission, for our intentions, consists of fulfilling the times of maintenance without diminishing the levels of security in the operation of the installation.

The qualification of the supervisor is greater to the one of the technician and its understanding of the dynamics of the system, is based on its experience and some level of received specific qualification.

In this scene the supervisor understands that an activity of maintenance badly made implies the necessity to remake the maintenance activity, treating to eliminate any possible latent error that can emerge during plant operation.

IV. Supervisor – technician relationship model

For the accomplishment of the model the following suppositions were made.

An activity of maintenance "*a*" so that its concretion requires of time "*T*" of a technician.

The technician notices that if follows the procedure the duration of "*a*" is "*T*"; but if it makes the activity modifying

the procedure can recover a time "*t*". Therefore the maintenance activity "*a*" will be finished in "*T-t*".

It will be denominated with "*y*" and "*1-y*" the strategies of action of the technician, which are to follow the procedure written or not to follow it. On the other hand the supervisor understands that the task must at the most be made in the time "*T*" and that depends on its active supervision that the technician indeed follows the procedure prescribed.

Also the supervisor understands that if the procedure is not followed it can require remaking the work incurring the necessity of a new period of time "*T*".

It must notice that the supervisor must control to more of a technician per time and therefore must choose a strategy so that assures the global efficiency of his work, perhaps not supervising smaller tasks, nor routine tasks or to technicians of its confidence among others.

It will be denominated with "*x*" and "*1-x*" the strategies of action of the supervisor, which are basically to supervise the use of the procedures or not to supervise it.

In Table I is shown the bimatrix game where the supervisor does not have the urgent necessity to supervise another activity, for that reason its loss when supervising to a technician who follows the procedure is unitary.

On the other hand the technician does not gain anything with following the procedure from his point of view, than to more satisfy the supervisor, who will not yield more time to him since this he depends on a programming of activities that is outside its reach. Based on these considerations the bi-matrix is clearly unbalanced; but it is adapted to try an approach to the behavior of the supervisor and the technician in a simple scene.

Tabla I. Bimatrix of the basic game

		Technician	
		Follow the procedure "*1-y*"	Not follow the procedure "*y*"
Supervisor	Supervise "*1-x*"	-1 -1	*-T t*
	Not supervise "*x*"	1 -1	*-T t*

Tabla II. Bimatrix of the case maintenance tasks periodically programmed

			Technician	
			Follow the procedure 0.999	Not follow the procedure 0.001
Supervisor	Supervise	0.9	-1 -1	*-T t*
	Not supervise	0.1	1 -1	*-T t*

V. Study of Cases

In the following, it will be developed three cases: maintenance tasks periodically programmed, use of written procedures and suitable use of control lists.

A. Maintenance tasks periodically programmed

Field data were obtained of reference [3]. These data are in himself the strategies followed so much by the supervisor as by the technician as opposed to different situations. They were compiled of a great amount of facilities of the nuclear scope in the United States.

In Table II it is shown the bimatrix for maintenance tasks periodically programmed. It is to say that it is in front of frequent tasks.

Solving table II it is obtained that the relation "*t/T*" is of 2 orders of magnitude.

That is to say, that would exist a fort incentive in the technicians in not following the procedure in tasks programmed periodically.

This agrees with the tendency founded in diverse facilities that take to the supervisor to fix a strategy oriented to the supervision of the task (supervises = 0,9).

In counterpart it forces the technician to adopt a coincident strategy with the level of control adopted by the supervisor (follows the procedure = 0.999). The decision of the technician is not independent of the strategic election of the supervisor, strongly is influenced by its knowledge.

For that reason the supervisor will have to not only make the supervision of the tasks that he can, but that in addition will have to make know the technicians which is his strategy of supervision. Of such way to resist the fort incentive that appears the technicians not to follow the procedure.

B. Use of written procedures

In Table III can be observed the proposal for the case of the control of the use of written procedures during a maintenance action.

Tabla III. Bimatrix of the case use of written procedures

			Technician	
			Follow the procedure 0.95	Not follow the procedure 0.05
Supervisor	Supervise	0.7	-1 -1	*-T t*
	Not supervise	0.3	1 -1	*-T t*

In the case of procedures controlled by security it is fundamental that the technician arranges and uses the written procedure during the maintenance action.

Not to have written procedures it is considered a problem of administrative control and his nonuse like a serious fault.

In this case the Supervisor has relaxed the supervision strategy. It must be note that these are extracted data of the daily reality of diverse facilities in the nuclear area.

This relaxation of the exigency of the use of the written procedures is reflected in the attitude of the Technician who in a 5% of the cases does not follow the procedure.

In other words, the procedure indicates *"to use the written procedure*" and its mandate is related to the importance of the component on which it is working or the complexity of the task to make or both.

The relation "*t/T"* is of one order of magnitude, which implies that before new manifestations of the supervisor to relax his attitude still more the technician will increase the amount of activities in which will not use the written procedures.

C. *Suitable use of control lists*

When a task that requires a series of steps is made, control lists are used. These lists are simply an enumeration of the steps that are due to follow to make a task.

In general they have relation with the actions to make to put in maintenance a component or to leave it ready for its operation, or with the steps necessary to disarm a component or to arm it after a repair.

In Table 4 the bimatrix is shown for the case of the control of suitable use of control lists.

For this case in individual it is observed that the strategy of the supervisor is not clear.

From the point of view of the technician the probability of being controlled in a great installation is low.

The relation "*t/T*" without concerning the decision of the Technician becomes infinite and this one is strongly motivated not to use the control lists.

Thus the supervisor will determine the strategy that follows but by other actions that are made in the installation to maintain the self-control.

Tabla IV. Bimatrix of the case use of control lists

			Technician			
			Follow the procedure		Not follow the procedure	
			0.999		0.001	
Supervisor	Supervise	0.5	-1	-1	*-T*	*t*
	Not supervise	0.5	1	-1	*-T*	*t*

The self-control of the technicians can be maintained by means of strategies of permanent retraining that have like mission to maintain present in the mind of the technician the level of danger which involve certain activities and the levels of defense that must be taken.

Another activity can be a campaign of awareness of the necessity to follow the procedures and the exemplification of the consequences of errors of commission.

VI. Discussion

The displayed examples are only one part of the analyzed total to determine the viability of the modeled errors of commission in diverse schemes (strategies) of control in industrial facilities.

It is possible to note as the examples allow clearly, still for the simplified cases analyzed, to be concluded with a "x-ray" of the tendency of the attitude of the technician as opposed to the determination of the supervisor to control it or not with certain probability.

It will be of interest to advance in the case for repetition of decision-makings that would be more similar to the real case.

The first case shows the importance of the understanding of the technician of the strong strategy of control of the supervisor, who will take a strategy against a strong motivation to not fulfill the procedure in activities programmed periodically.

In the second case, the relaxation of the control strategy leads to the increase of tasks without the use of the procedures written, diminishing the levels of benefit in 2 orders of magnitude. This implies that when the relation "*t/T*" is in 3 orders of magnitude the incentive not to follow the procedure he is too strong like so that the technician it resists to the same one.

In the last case the relation "*t/T*" becomes infinite and with no need to recognize the strategy of the technician. Which leads to look for other tools that serve as sustenance to a suitable selection as the strategy on the part of the technician, since the supervisor will not be the source of reference for the decision making.

VII. Conclusion

The aim to the authors is to model human errors by the application of the Theory of Games.

To begin the study it was visited two nuclear reactors of Argentina: RA-6 and RA-3 nuclear reactors where some examples were gathering.

With the intention of testing the Theory of Games in the application to the human error analysis it was had an exploratory but no exhaustive study.

Different methods have been developed to calculate probabilities. The authors hope to obtain the possibility of can evaluate with this approach human tendencies at different

situations.

The study of the application of simple models based on the Theory of Games for the study of errors of commission has demonstrated to be of utility in this initial stage.

It was possible to analyze a series of cases that demonstrate the generosity of this theory and encourage to continue deepening the study.

The future activities in this line of investigation are related with two aspects. The first increase of the complexity of the model, in such way to incorporate additional elements like the scenes in which the decision making is based in previous experiences of the conduct of the supervisor and *viceversa*, among others.

The second aspect is the gathering of information of facilities in Argentina to verify the possibility of interpretation of the behavior in the national context.

Finally it is hoped to be able to use the model generated in prospective form. That is to say, to be able to foretell the behavior of the technicians knowing the organizational aspects related to the control, the retraining, the initial qualification, etc.

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REFERENCES

[1] F. Costales, "*Teoría de Juegos*", República Bolivariana de Venezuela, i.u.p. Santiago Mariño, San Cristóbal, 2000.

[2] D. Gertman and H. Blackman, *Human Reliability & Safety Analysis Data Handbook*, Wiley, 1994.

[3] NRC, *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications*, Nureg/CR-1278, USA, 1983.

[4] Björn Zeiger, *CREAM Cognitive Reliability and Error Analysis Method*, Department for Computer Science, University of Paderborn, 2005.

[5] NRC, *Technical Basis and Implementation Guidelines for A Technique for Human Event Analysis (ATHEANA), Nureg-1624, Rev. 1, USA, 2000.*

[6] U. S. Nuclear Regulatory Commission – Sandia National Laboratories, *"Philosophy of ATHEANA",* 1999.

[7] NRC, *Evaluation on Human Reliability Analysis Methods Against Good Practices,* draft report for comment, Nureg-1842, USA, 2006.

[8] Institute for Energy Technology, *Human Error and models of behaviours,* IFE/HRE/E-2005/031, 2006.

[9] A G Foord & W G Gulland, 2007, March, 20, *Can technology eliminate human error?, Availabe: http://www.4-sightconsulting.co.uk/ Current_Papers/Technology_and_Human_Error/technology_and_human_error.html*

[10] H. A. P. Blom, J. Daams and H. B. Nijhuis, *"Human cognition modelling in Air Traffic Management safety assessment"*, National Aerospace Laboratory, NLR-TP-2001-636, 2001.