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A HUMAN ERROR PROBABILITY ESTIMATE METHODOLOGY BASED ON FUZZY INFERENCE AND EXPERT JUDGMENT ON NUCLEAR PLANTS

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ABSTRACT

Recent studies point human error as an important factor for many industrial and nuclear accidents: Three Mile Island (1979), Bhopal (1984), Chernobyl and Challenger (1986) are classical examples. Human contribution to these accidents may be better understood and analyzed by using Human Reliability Analysis (HRA), which has being taken as an essential part on Probabilistic Safety Analysis (PSA) of nuclear plants. Both HRA and PSA depend on Human Error Probability (HEP) for a quantitative analysis. These probabilities are extremely affected by the Performance Shaping Factors (PSF), which has a direct effect on human behavior and thus shape HEP according with specific environment conditions and personal individual characteristics which are responsible for these actions. This PSF dependence raises a great problem on data availability as turn these scarcely existent database too much generic or too much specific. Besides this, most of nuclear plants do not keep historical records of human error occurrences. Therefore, in order to overcome this occasional data shortage, a methodology based on Fuzzy Inference and expert judgment was employed in this paper in order to determine human error occurrence probabilities and to evaluate PSF's on performed actions by operators in a nuclear power plant (IEA-R1 nuclear reactor). Obtained HEP values were compared with reference tabled data used on current literature in order to show method coherence and valid approach. This comparison leads to a conclusion that this work results are able to be employed both on HRA and PSA enabling efficient prospection of plant safety conditions, operational procedures and local working conditions potential improvements.

1. INTRODUCTION

There is an alarming relation between the number of system faults and the proportion of human error contribution. Although there is a high automation level in actual systems, still there is an important dependence on human-machine interaction for their maintenance or management. Human action is present all over the system life cycle, since the project until its disposal [8].

A human error is characterized as a divergence between the realized action and the action that should have been taken. This divergence must have an effect that goes beyond the system required tolerance [8]. Different error types where human error can occur are classified in two classes: omission error (do not performing system required action) and commission error (incorrect performance on required action or performing system non-required action) [16].

Human Error Probability (HEP) is defined as the ratio between the number of performed errors and the number of given opportunities for error to occur. Human Reliability is the probability that an operator will reasonably perform a system required task in a determined time, without performing any other action that should degrade the system [2]. The usual tool employed to measure human reliability is Human Reliability Analysis (HRA) which has as its goal to perform a human performance prediction and evaluation, using Human Error occurrence Probability (HEP) [19]. There are factors that act on human performance (Performance Shaping Factors – PSF's) specially when related to human-machine environment. Among these, the external factors are equipment, procedures or environment. Internal factors are individual operator characteristics, motivations, abilities and dexterity. These factors have direct effect on behavior and shape HEP for the specific analyzed situation characteristics. The PSF's, depending on their nature, have the property of increase or diminish HEP [2].

The Probabilistic Safety Assessment (PSA) is an important tool for quantifying the existent operational risk on nuclear reactors or other potentially risky installations. Using this analysis, the actual accidents occurrence probabilities are obtained and their consequences are evaluated in order to get a numerical estimate of how safe that installation is [10 and 15]. PSA are modelled based on Event Tree and Fault Tree which are analised to obtain the basic events which may have as cause: a component failure and/or human error. Human error events inside PSA analysis are detailed in [5, 9 and 15]. The quantification of HRA or of the basic events inside a PSA when human error is the main cause, leads to a consequent need of human error probability data of basic actions for different tasks and a quantitative representation of possible influence of PSF's on these actions [2, 5, 8, 16 and 20].

Unfortunately it is not possible to find human error data as easily as is to find component faults data (all usually tabled). The scarce available human error databases are usually or very specific or generic due to PSF peculiarities. Besides that, few plants keep regular registry of human error occurrence historical data. In this context, expert judgment taken as subjective probability evaluation has been an important tool to develop a human error database for HRA / PSA. Subjective judgment is necessary due to an impossible precise and objective evaluation. This judgment is done based on natural language (linguistic expressions) evaluations [14 and 18].

Many studies [1, 7, 11, 12, 14, 17 and 18] have shown that fuzzy logic can provide an exclusive method for translating common human expressions (vague and imprecise) into mathematical and logical variables. In order to overcome these intrinsic barriers on HEP and PSF determination, this work uses a methodology based on Fuzzy Logic combined with expert judgment to determine human error occurrence probabilities and to evaluate Human Performance Shaping Factors (PSF's) on performed actions in a nuclear power plant.

2. EXPERT GROUP FORMATION

In order to demonstrate the employed methodology effectiveness, IEA-R1 (Ipen-Cnen, Sp, Brazil) nuclear reactor was chosen as scenery for a study of nuclear reactor operator actions based on their response to an emergency situation described in their Local Emergency Plan. Both to obtain HEP as to evaluate PSF it was necessary to elicit experts knowledge through interviews and questionnaires. A group of experts was selected among IEA-R1 actual operators. These experts are asked to make their evaluations based on their own experience and knowledge. As these attributes have considerable variation among different experts, an Expert Importance Grade (EIG) was introduced to weight their answers on evaluating their relative importance to overall reliability analysis [1, 7 and 12]. EIG factor was based on educational level and operation experience time as can be seen on Table 1.

Table 1. EIG Criteria

EDUCATIONAL LEVEL	POINTS (P1)	TIME OF EXPERIENCE (years)	POINTS (P2)
PhD	5	28 - 35	5
Master	4	21 – 27	4
Specialist	3	14 – 20	3
Graduate	2	7 – 13	2
Medium Degree	1	1 – 6	1

Effectively eleven IEA-R1 operators took part on this work. A number of points (P1) was attributed to each one according with their educational level and P2 points according to professional experience time. The group used to evaluations was composed of the seven higher EIG scores operators as shown on Table 2. Expert EIG factor was evaluated based on Equation 1 as follows:

$$\mathrm{EIG}i = \frac{\mathrm{PE}i}{\sum_{i=1}^{7} \mathrm{PE}i} \tag{1}$$

Table 2. Expert Importance Grade (EIG)

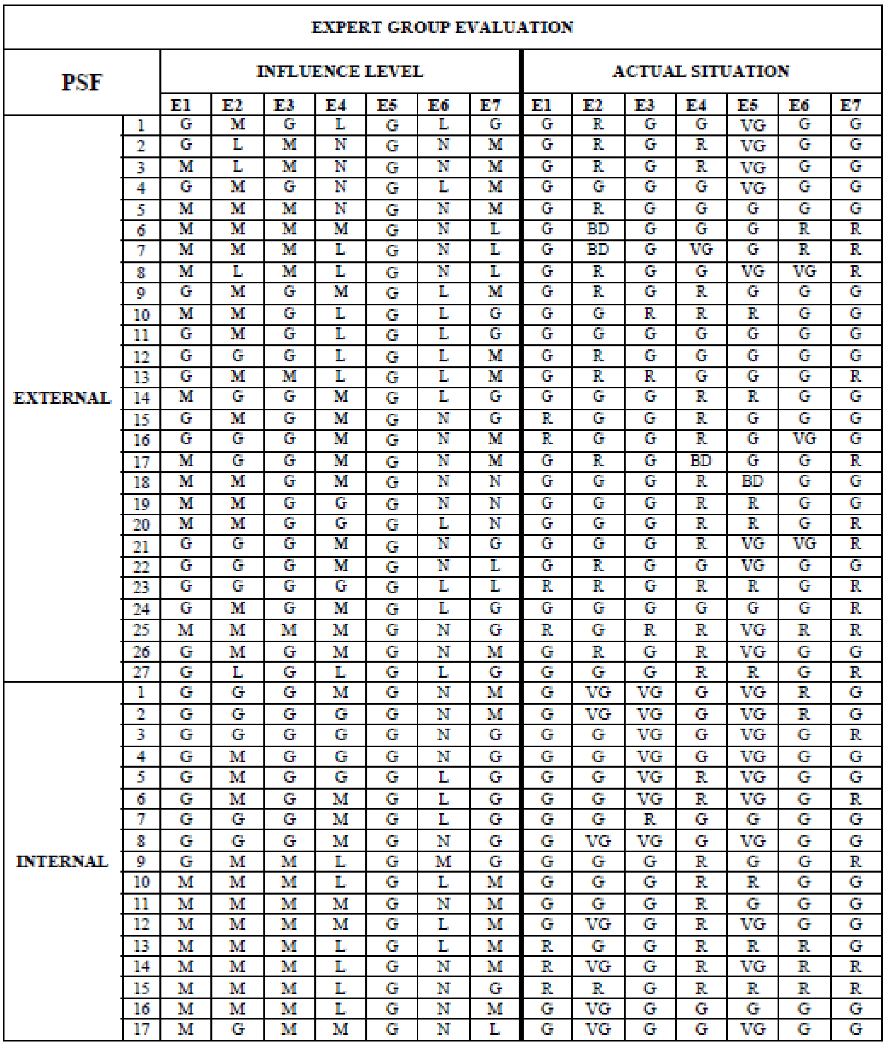
EXPERT (Ei)	EDUCATIONAL LEVEL	P1	EXPERIENCE (years)	P2	PEi (P1 + P2)	FACTOR (EIG)
E1	Master	4	30	5	9	0,25
E2	Graduate	2	32	5	7	0,20
E3	Graduate	2	27	4	6	0,17
E4	Medium Degree	1	18	3	4	0,11
E5	Graduate	2	10	2	4	0,11
E6	Medium Degree	1	12	2	3	0,08
E7	Medium Degree	1	10	2	3	0,08
TOTAL = Σ PEi					36	1

3. HUMAN PERFORMANCE SHAPING FACTORS EVALUATION

Evaluation was done with two main purposes: determine PSF influence level on operator performance when action happens in response to an emergence situation and identify how the expert (operator) perceives each related factor actual situation, both the ones related to activity local environment as those related exclusively to themselves. The probable selected factors that should influence operator performance were chosen based on established headlines found on [2, 3 and 7].

Although three different linguistic values (fuzzy labels) should be enough to implement the Fuzzy Logic System (FLS), questionnaires were constructed based on a wider range of linguistic options in order to extract maximum discrimination on their probability estimate opinion. Their subjective evaluation was based on the following linguistic terms: **PSF Influence Level:** N – no influence, L – little influence, M – moderate influence and G – great influence; **PSF Actual Situation:** TBD - too bad situation, BD - bad situation, R – regular situation, G – good situation and VG - very good situation. PSF evaluation performed by Expert Group is shown on Table 3.

Table 3. PSF - Expert Group Evaluation.



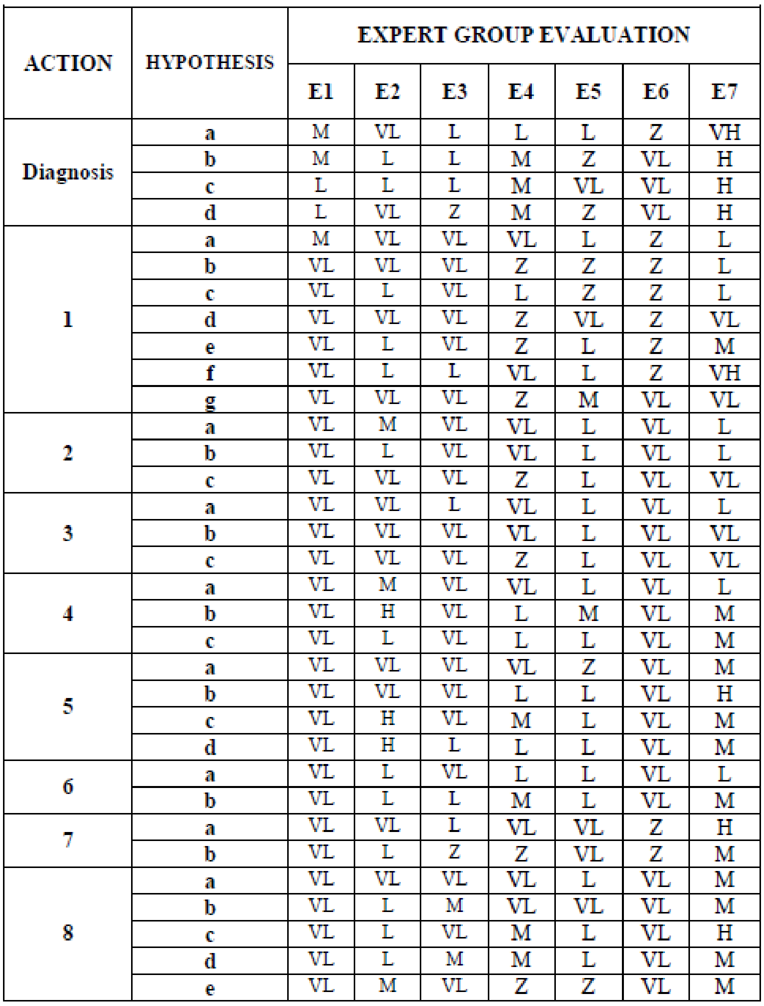
EXPERT GROUP EVALUATION															
PSF		INFLUENCE LEVEL							ACTUAL SITUATION						
		E1	E2	E3	E4	E5	E6	E7	E1	E2	E3	E4	E5	E6	E7
EXTERNAL	1	G	M	G	L	G	L	G	G	R	G	G	VG	G	G
	2	G	L	M	N	G	N	M	G	R	G	R	VG	G	G
	3	M	L	M	N	G	N	M	G	R	G	R	VG	G	G
	4	G	M	G	N	G	L	M	G	G	G	G	VG	G	G
	5	M	M	M	N	G	N	M	G	R	G	G	G	G	G
	6	M	M	M	M	G	N	L	G	BD	G	G	G	R	R
	7	M	M	M	L	G	N	L	G	BD	G	VG	G	R	R
	8	M	L	M	L	G	N	L	G	R	G	G	VG	VG	R
	9	G	M	G	M	G	L	M	G	R	G	R	G	G	G
	10	M	M	G	L	G	L	G	G	G	R	R	R	G	G
	11	G	M	G	L	G	L	G	G	G	G	G	G	G	G
	12	G	G	G	L	G	L	M	G	R	G	G	G	G	G
	13	G	M	M	L	G	L	M	G	R	R	G	G	G	R
	14	M	G	G	M	G	L	G	G	G	G	R	R	G	G
	15	G	M	G	M	G	N	G	R	G	G	R	G	G	G
	16	G	G	G	M	G	N	M	R	G	G	R	G	VG	G
	17	M	G	G	M	G	N	M	G	R	G	BD	G	G	R
	18	M	M	G	M	G	N	N	G	G	G	R	BD	G	G
	19	M	M	G	G	G	N	N	G	G	G	R	R	G	G
	20	M	M	G	G	G	L	N	G	G	G	R	R	G	R
	21	G	G	G	M	G	N	G	G	G	G	R	VG	VG	R
	22	G	G	G	M	G	N	L	G	R	G	G	VG	G	G
	23	G	G	G	G	G	L	L	R	R	G	R	R	G	R
	24	G	M	G	M	G	L	G	G	G	G	G	G	G	R
	25	M	M	M	M	G	N	G	R	G	R	R	VG	R	R
	26	G	M	G	M	G	N	M	G	R	G	R	VG	G	G
	27	G	L	G	L	G	L	G	G	G	G	R	R	G	R
INTERNAL	1	G	G	G	M	G	N	M	G	VG	VG	G	VG	R	G
	2	G	G	G	G	G	N	M	G	VG	VG	G	VG	R	G
	3	G	G	G	G	G	N	G	G	G	VG	G	VG	G	R
	4	G	M	G	G	G	N	G	G	G	VG	G	VG	G	G
	5	G	M	G	G	G	L	G	G	G	VG	R	VG	G	G
	6	G	M	G	M	G	L	G	G	G	VG	R	VG	G	R
	7	G	G	G	M	G	L	G	G	G	R	G	G	G	G
	8	G	G	G	M	G	N	G	G	VG	VG	G	VG	G	G
	9	G	M	M	L	G	M	G	G	G	G	R	G	G	R
	10	M	M	M	L	G	L	M	G	G	G	R	R	G	G
	11	M	M	M	M	G	N	M	G	G	G	R	G	G	G
	12	M	M	M	M	G	L	M	G	VG	G	R	VG	G	G
	13	M	M	M	L	G	L	M	R	G	G	R	R	R	G
	14	M	M	M	L	G	N	M	R	VG	G	R	VG	R	R
	15	M	M	M	L	G	N	G	R	R	G	R	R	R	R
	16	M	M	M	L	G	N	M	G	VG	G	G	G	G	G
	17	M	G	M	M	G	N	L	G	VG	G	G	VG	G	G

4. HUMAN ERROR PROBABILITY EVALUATION

HEP evaluation took into consideration actions described to contain the event: "Transient requiring the SCRAM system activation and with this activation failing on turning reactor off", classified on IEA-R1 Local Emergency Plan as "Ipen Emergency". Each action to contain the event is described in an appropriate procedure, for which operator error occurrence hypothesis were elaborated and for which probabilities were subjected to evaluation.

As the previous PSF procedure, three linguistic values should be enough to FLS implementation, but experts were asked to classify error occurrences probability into five different levels: Z – zero error occurrence probability, VL – very low occurrence probability, L – low occurrence probability, M – moderate occurrence probability, H – high occurrence probability, VH – very high occurrence probability. HEP Expert Group evaluation is shown on Table 4.

Table 4. Expert Group Evaluation of HEP



ACTION	HYPOTHESIS	EXPERT GROUP EVALUATION						
		E1	E2	E3	E4	E5	E6	E7
Diagnosis	a	M	VL	L	L	L	Z	VH
	b	M	L	L	M	Z	VL	H
	c	L	L	L	M	VL	VL	H
	d	L	VL	Z	M	Z	VL	H
1	a	M	VL	VL	VL	L	Z	L
	b	VL	VL	VL	Z	Z	Z	L
	c	VL	L	VL	L	Z	Z	L
	d	VL	VL	VL	Z	VL	Z	VL
	e	VL	L	VL	Z	L	Z	M
	f	VL	L	L	VL	L	Z	VH
	g	VL	VL	VL	Z	M	VL	VL
2	a	VL	M	VL	VL	L	VL	L
	b	VL	L	VL	VL	L	VL	L
	c	VL	VL	VL	Z	L	VL	VL
3	a	VL	VL	L	VL	L	VL	L
	b	VL	VL	VL	VL	L	VL	VL
	c	VL	VL	VL	Z	L	VL	VL
4	a	VL	M	VL	VL	L	VL	L
	b	VL	H	VL	L	M	VL	M
	c	VL	L	VL	L	L	VL	M
5	a	VL	VL	VL	VL	Z	VL	M
	b	VL	VL	VL	L	L	VL	H
	c	VL	H	VL	M	L	VL	M
	d	VL	H	L	L	L	VL	M
6	a	VL	L	VL	L	L	VL	L
	b	VL	L	L	M	L	VL	M
7	a	VL	VL	L	VL	VL	Z	H
	b	VL	L	Z	Z	VL	Z	M
8	a	VL	VL	VL	VL	L	VL	M
	b	VL	L	M	VL	VL	VL	M
	c	VL	L	VL	M	L	VL	H
	d	VL	L	M	M	L	VL	M
	e	VL	M	VL	Z	Z	VL	M

5. FUZZY MODELLING OF EVALUATIONS

Fuzzy theory was introduced in 1965 by L.A.Zadeh as a tool to deal with imprecision and to enable computing logical inference based on linguistic terms estimates [6 and 13]. This tool is implemented by the called Fuzzy Logic System (FLS) which generally performs a nonlinear mapping of input data (feature) vector into a scalar output. The FLS evaluates suitable rules based on linguistic therms in order to obtain the decision values as output. Fuzzy evaluation is based on Fuzzy Set Theory which enables "if-then" similar rules creation and consequent fuzzy reasoning [6].

A fuzzy set is defined by a group of elements of a Universe of Discourse $\boldsymbol{X}$ in which each element pertains to a certain set with a "membership grade". The characteristic function which associates each element with this membership grade is called "membership function" (μ) and it is usually normalized with real values varying between 0 and 1, and is formally described by: $\mu A : X \rightarrow [0,1]$, where $\boldsymbol{A}$ is a fuzzy subset and $\boldsymbol{X}$ is the universe of discourse [4 and 13].

Three different FLS were implemented in this work:

- PSF Influence Level (INFL_PSF);
- PSF Actual Situation (SIT_PSF);
- Human Error Probability (HEP).

The dimension of a FLS is exponentially proportional to the number of input and output variables, and some optimization of global inference is necessary to obtain final estimates.

Fuzzy inference was performed in two steps as described below:

First Inference Phase

The opinions from the operators with smaller EIG factors (E4, E5, E6 and E7) were aggregated into each FLS estimating an output value $R_{(E4\text{-}E7)}$ for INFL_PSF, SIT_PSF and HEP representing this subset opinion.

Second Inference Phase

The previous aggregated opinion $R_{(R4\text{-}R7)}$ was used as input to the FLS where higher score (higher EIG factors) operators opinions were used as inputs also. Second phase FLS were evaluated using E1, E2, E3 and $R_{(R4\text{-}R7)}$ as inputs.

5.1. Linguistic Variables Definition (Fuzzy Sets)

Universe of Discourse parameters and reference values used as FLS linguistic input and output variables were based on recommended values [2, 8, 9 and 16]. Tables 5, 6 and 7 show these values for each phase in each implemented FLS.

Table 5. Linguistic Variables - FLS-INFL_PSF

Type	Variables		Universe of Discourse	Linguistic Values	Reference Values
	1st Phase	2nd Phase			
Input	E4, E5, E6 e E7	E1, E2, E3 e $R_{(E4-E7)}$	0 - 10	N – no influence	0
				L – little influence	2
				M – moderate influence	5
				G – great influence	10
Output	$R_{(E4-E7)}$	INFL_PSF	0 –10	N – no influence	INFL_PSF < 1
				L – little influence	1 ≤ INFL_PSF < 3
				M – moderate influence	3 ≤ INFL_PSF < 7
				G – great influence	7 ≤ INFL_PSF ≤ 10

Table 6. Linguistic Variables - FLS-SIT_PSF

Tipo	Variables		Universe of Discourse	Linguistic Values	Reference Values
	1stPhase	2nd Phase			
Input	E4, E5, E6 e E7	E1, E2, E3 e $R_{(E4-E7)}$	0,1 – 10	VG - very good situation	0,1
				G – good situation	0,5
				R - regular situation	1
				BD - bad situation	5
				TBD - too bad situation	10
Output	$R_{(E4-E7)}$	SIT_PSF	0,1 –10	VG - very good the situation	0,1 ≤ SIT_PSF < 0,4
				G – good the situation	0,4 ≤ SIT_PSF < 0,8
				R - regulate the situation	0,8 ≤ SIT_PSF < 3
				BD - bad the situation	3 ≤ SIT_PSF < 7
				TBD - too bad the situation	7 ≤ SIT_PSF ≤ 10

Table 7. Linguistic Variables - FLS-HEP

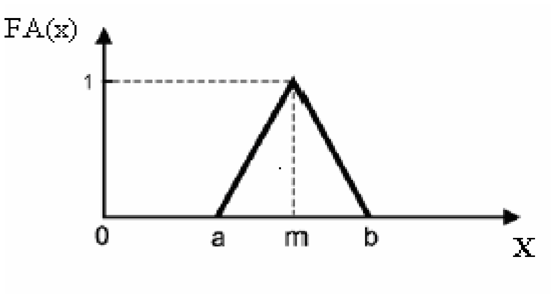
Type	Variables		Universe of Discourse	Linguistic Values	Reference Values
	1st Phase	2nd Phase			
Input	E4, E5, E6 e E7	E1, E2, E3 e $R_{(E4-E7)}$	0 - 1	Z – zero;	0
				VL – very low	0,0001
				L – low;	0,001
				M – moderate	0,01
				H – high	0,1
				VH – very high	1
Output	$R_{(E4-E7)}$	HEP	0 –1	Z – zero;	HEP < 0,00005
				VL – very low	0,00005 ≤ HEP < 0,0005
				L – low;	0,0005 ≤ HEP < 0,005
				M – moderate	0,005 ≤ HEP < 0,05
				H – high	0,05 ≤ HEP < 0,5
				VH – very high	0,5 ≤ HEP ≤ 1

One important aspect of the FLS shown on above tables is that their effective values used as input on each FLS are based on input reference values and each expert's general consensus is classified into a reference value range to obtain the correspondent linguistic value. Therefore all input values and expected output values on FLS are treated as "Reference Values".

5.2. FLS Implementation

The FLS implemented in this work were done based on MATLAB® Version 7.0.1 Fuzzy Logic Toolbox. All three FLS were implemented base on Mamdani's inference system with centroid defuzzification method. Inference system is based on fuzzy implication evaluation of classical logical proposition: "if *x* is *A* then *y* is *B"*, where *A* and *B* are linguistic values defined by fuzzy sets on the X and Y ranges (Universes of discourse) respectively. The "if-part" of the rule "*x* is *A*" is called the *antecedent* or premise, while the "then-part" of the rule "*y* is *B*" is called the *consequent* or conclusion [6].

Three different fuzzy values for each linguistic variable were defined. Membership functions were triangular shaped as shown of Figure 1.



$$F_{A(x)} = \left| \begin{array}{l} (x-a) / (m-a),\ a \le x \le m \\ (x-b) / (a-b),\ m \le x \le b \\ 0,\ \text{otherwise} \end{array} \right.$$

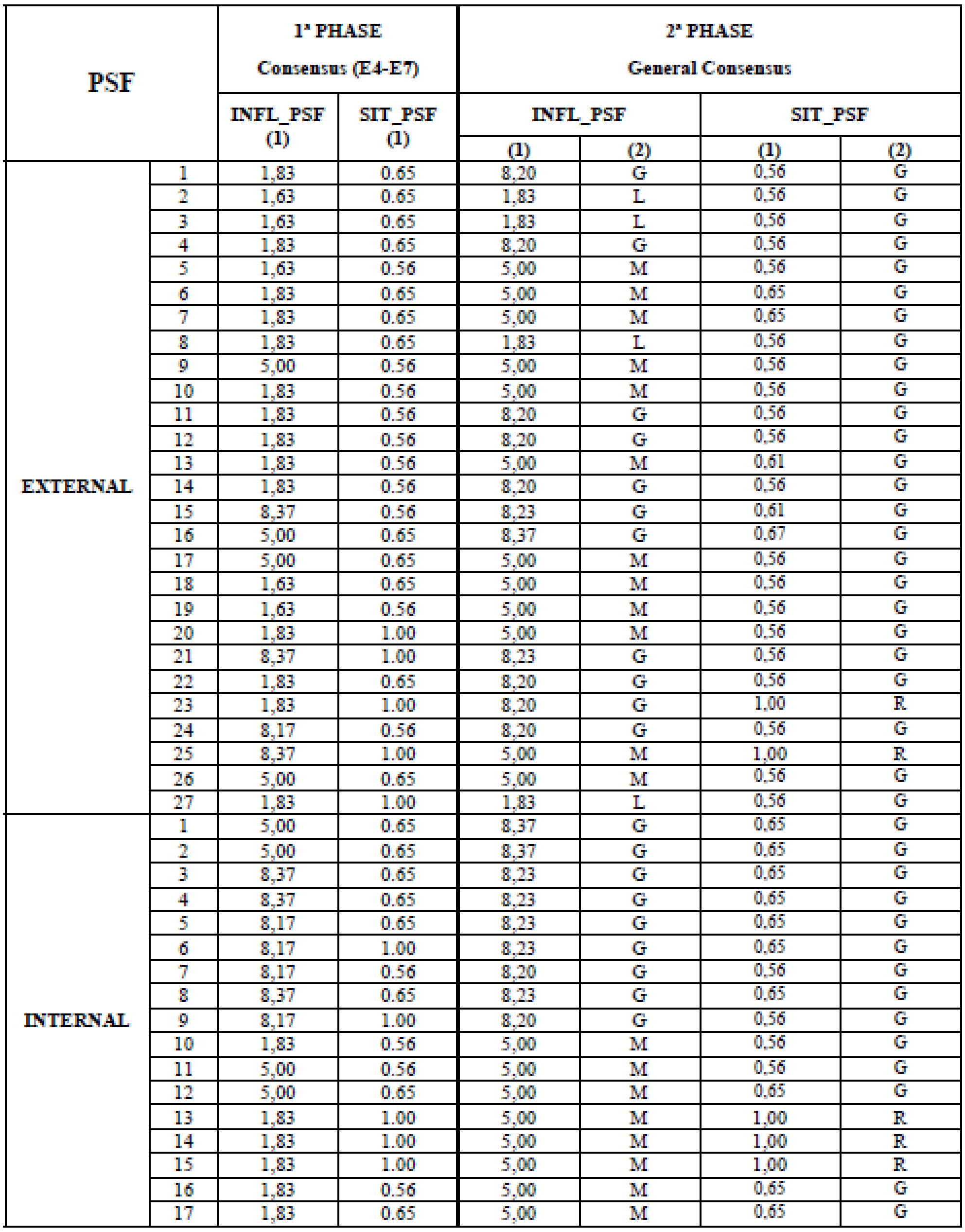
Figure 1. Triangular Membership Function

The rules set established for each FLS phase was implemented through possible combinations of defined linguistic values inputs. The number of rules set used was 81 rules (3^4), where 3 is the number of variables for 4 inputs. Expert Importance Grade (EIG) (Eq. 1) was considered on rules implementation for each FLS, where each linguistic expression evaluated by an expert (ex. VL, H, VH, M,…) was weighted with its correspondent EIG value. Based on the rules the linguistic value with bigger EIG sum was taken as output as done previously by other studies [1 and 12].

6. RESULTS AND DISCUSSION

The linguistic values associated with expert evaluations presented on Tables 3 and 4 were rewritten according with their respective reference values on Tables 5, 6, and 7 and appropriately formatted as inputs to correspondents FLS, generating the results in each phase presented on Tables 8 and 9.

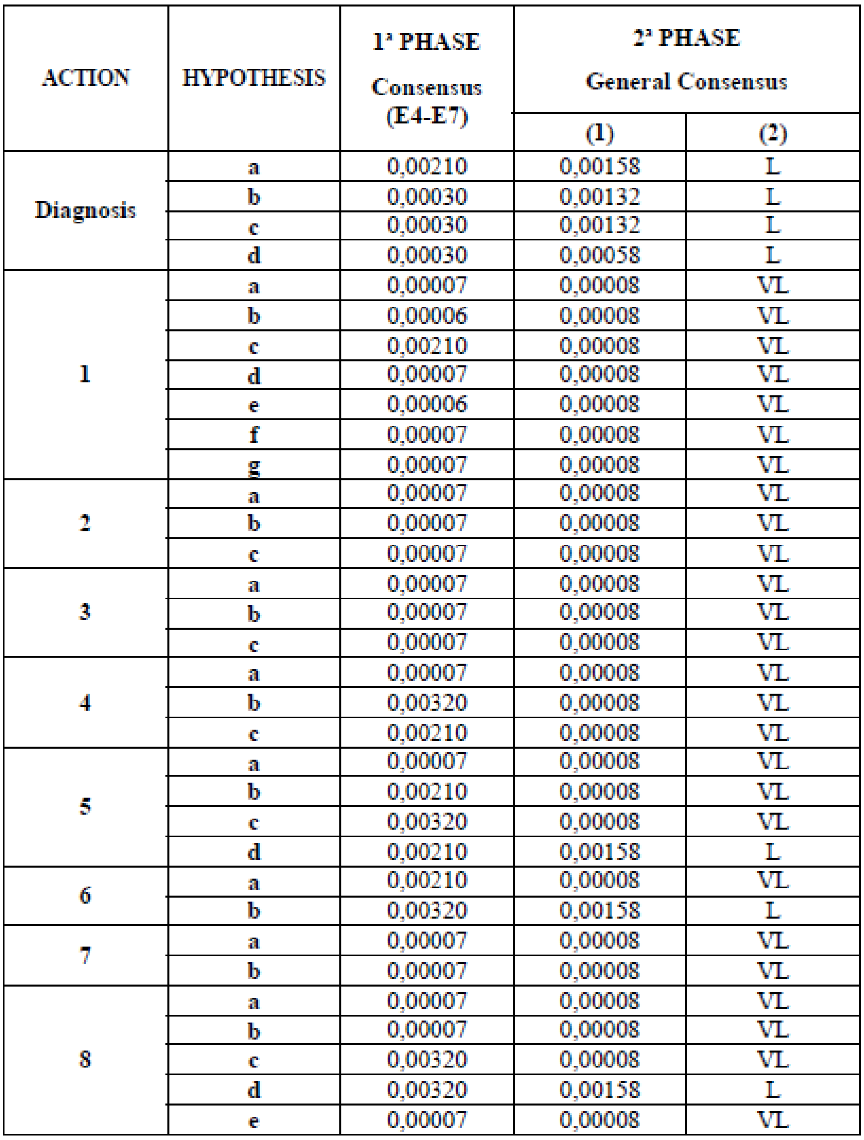
Table 8. Final Results of Evaluations of PSF



PSF		1ª PHASE Consensus (E4-E7)		2ª PHASE General Consensus			
		INFL_PSF (1)	SIT_PSF (1)	INFL_PSF		SIT_PSF	
				(1)	(2)	(1)	(2)
EXTERNAL	1	1,83	0.65	8,20	G	0,56	G
	2	1,63	0.65	1,83	L	0,56	G
	3	1,63	0.65	1,83	L	0,56	G
	4	1,83	0.65	8,20	G	0,56	G
	5	1,63	0.56	5,00	M	0,56	G
	6	1,83	0.65	5,00	M	0,65	G
	7	1,83	0.65	5,00	M	0,65	G
	8	1,83	0.65	1,83	L	0,56	G
	9	5,00	0.56	5,00	M	0,56	G
	10	1,83	0.56	5,00	M	0,56	G
	11	1,83	0.56	8,20	G	0,56	G
	12	1,83	0.56	8,20	G	0,56	G
	13	1,83	0.56	5,00	M	0,61	G
	14	1,83	0.56	8,20	G	0,56	G
	15	8,37	0.56	8,23	G	0,61	G
	16	5,00	0.65	8,37	G	0,67	G
	17	5,00	0.65	5,00	M	0,56	G
	18	1,63	0.65	5,00	M	0,56	G
	19	1,63	0.56	5,00	M	0,56	G
	20	1,83	1.00	5,00	M	0,56	G
	21	8,37	1.00	8,23	G	0,56	G
	22	1,83	0.65	8,20	G	0,56	G
	23	1,83	1.00	8,20	G	1,00	R
	24	8,17	0.56	8,20	G	0,56	G
	25	8,37	1.00	5,00	M	1,00	R
	26	5,00	0.65	5,00	M	0,56	G
	27	1,83	1.00	1,83	L	0,56	G
INTERNAL	1	5,00	0.65	8,37	G	0,65	G
	2	5,00	0.65	8,37	G	0,65	G
	3	8,37	0.65	8,23	G	0,65	G
	4	8,37	0.65	8,23	G	0,65	G
	5	8,17	0.65	8,23	G	0,65	G
	6	8,17	1.00	8,23	G	0,65	G
	7	8,17	0.56	8,20	G	0,56	G
	8	8,37	0.65	8,23	G	0,65	G
	9	8,17	1.00	8,20	G	0,56	G
	10	1,83	0.56	5,00	M	0,56	G
	11	5,00	0.56	5,00	M	0,56	G
	12	5,00	0.65	5,00	M	0,65	G
	13	1,83	1.00	5,00	M	1,00	R
	14	1,83	1.00	5,00	M	1,00	R
	15	1,83	1.00	5,00	M	1,00	R
	16	1,83	0.56	5,00	M	0,65	G
	17	1,83	0.65	5,00	M	0,65	G

1- Reference Values **2 – Linguistic Values**

Table 9. Final Results of Evaluations of HEP



ACTION	HYPOTHESIS	1ª PHASE Consensus (E4-E7)	2ª PHASE General Consensus	
			(1)	(2)
Diagnosis	a	0,00210	0,00158	L
	b	0,00030	0,00132	L
	c	0,00030	0,00132	L
	d	0,00030	0,00058	L
1	a	0,00007	0,00008	VL
	b	0,00006	0,00008	VL
	c	0,00210	0,00008	VL
	d	0,00007	0,00008	VL
	e	0,00006	0,00008	VL
	f	0,00007	0,00008	VL
	g	0,00007	0,00008	VL
2	a	0,00007	0,00008	VL
	b	0,00007	0,00008	VL
	c	0,00007	0,00008	VL
3	a	0,00007	0,00008	VL
	b	0,00007	0,00008	VL
	c	0,00007	0,00008	VL
4	a	0,00007	0,00008	VL
	b	0,00320	0,00008	VL
	c	0,00210	0,00008	VL
5	a	0,00007	0,00008	VL
	b	0,00210	0,00008	VL
	c	0,00320	0,00008	VL
	d	0,00210	0,00158	L
6	a	0,00210	0,00008	VL
	b	0,00320	0,00158	L
7	a	0,00007	0,00008	VL
	b	0,00007	0,00008	VL
8	a	0,00007	0,00008	VL
	b	0,00007	0,00008	VL
	c	0,00320	0,00008	VL
	d	0,00320	0,00158	L
	e	0,00007	0,00008	VL

1- Reference Values **2 – Linguistic Values**

The numeric values presented on these tables are system final resultants and can be directly employed on PSA / HRA quantification. The Linguistic Values were obtained through comparison with Reference Values output ranges shown on Tables 5, 6 and 7.

Information obtained on Table 8 is very important to situations in which better work conditions are necessary and desirable, through prioritizing more influent PSF's. It is possible to observe more than 90% of PSF factors to have good evaluations (G). SIT_PSF final results can be directly applied to HEP.

Values obtained on HEP estimates shown on Table 9 were compared with data from tables 20-18, 20-19, 20-23, 20-25, 20-26 and 20-32 of Swain Handbook [2] and Kletz [16] table 7.3 and were consistently similar for similar actions.

7. CONCLUSION

HEP data shortage can be efficiently and reliably overcame by applying methodology exposed on this work both for PSA as to HRA. This methodology enables solid mathematical treatment for subjective and uncertainty subject measurements through fuzzy logic variables implementation based on expert evaluation.

HEP and PSF obtained values are apt to be applied both on HRA as on PSA for this installation enabling possible important improvements to the system. Expert's judgment use is justified by the already mentioned highlighted human behavior dependence on PSF's which model it. These PSF's are specific and strongly dependant on local factors and on personal and environment characteristics.

Among others this work shows some potential installation benefits:

- Appropriate guidelines for Classification And Data Collection based on human errors;
- Possible HEP application on Probabilistic Safety Assessment – PSA, which could reduce accident risks through feedback information availability to project and maintenance analysis;
- Environmental conditions improvement by evaluation of PSF's actual situation which can contribute to find specific errors;
- Detection of potential operational procedure improvements by indentification of the probable human errors;

The presented methodology, with appropriate changes can be adapted to other installations where human errors registry maybe scarce using other experts and environment references.

Suggestions for future work

Introducing small changes the implemented FLS can be applied to evaluate other installations enabling similar tools for future application where database can be organized and structured based on HEP inference results.

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