International Journal of Pure and Applied Mathematics
Volume 117 No. 21 2017, 311-325
ISSN: 1311-8080 (printed version); ISSN: 1314-3395 (on-line version)
url: http://www.ijpam.eu
Special Issue
ijpam.eu

# Some Aspects of Human Error Analysis Using Fuzzy Relations

[1]R. Sujatha, [2]V. Sharmila, [3]P. Hema, [4]M. Amruth Varshinee and [5]A. Sakthi Prasnath
[1]Department of Mathematics.
sujathar@ssn.edu.in
[2]Department of Mathematics.
[3,4,5]Department of Chemical Engineering,
SSN College of Engineering,
Kalavakkam.

## Abstract

The study of human error mechanism is an important foundation for human reliability analysis. The performance influencing factors causing human error mainly consist of organisational factors, situational factors and individual factors. The main aim of this work is to analyse the pressure levels of employees. Pressure being an individual factor has a direct impact on human error. The task scheduling is taken as the root for the analysis. The task scheduling is categorized into three levels namely, unreasonable, acceptable and reasonable. The task scheduling is practically implemented as workload through operational procedure. Workload and pressure are often related. These factors are cognitive in nature with uncertainty. These relational uncertainties are well captured using fuzzy relational theory. In this paper, fuzzy max-min composition is used to compute the fuzzy relation between the operational procedure, workload and pressure. This approach will give an insight on the pressure levels of employees based on which suitable corrective measure can be adopted for improvement of the overall system.

**Key Words:**Human error probability, performance influencing factors, fuzzy relation, fuzzy max-min composition.

# 1. Introduction

Human reliability and human error probability (HEP) are important tasks due to the human contribution in reliability analysis. Fundamental difference is that the human reliability is defined as the probability that the job or task will be done successfully by the individual at any specified stage in system operation with minimum time while the human error is defined as the failure to perform a given task/job which could cause damage to equipment and property or disruption of planned operations [1, 2]. In general, the human reliability analysis (HRA) has been widely applied in many areas such as probabilistic risk assessment in nuclear power plants and safety systems [3], marine [4, 5], medical [6], transport and railway systems [2, 7], aircraft maintenance [8], oil and gas refinery [9] and many other industries [10].

The important aspects of fuzzy set theory rely on its ability to interpret the vague information. It is applied to model the systems that are difficult to define precisely. In reliability analysis, the survival probabilities of system components are treated as exact values but this precision is not true in the real applications [11]. There exits some uncertainty in the survival probabilities obtained from experiment. Main aspects of uncertainty are fuzziness and randomness. For randomness, uncertainty arises due to variability or stochastic, whereas in fuzziness an uncertainty occurs due to lack of information, ignorance and/or subjectivity. Several researchers worked on fuzzy concepts in reliability analysis to estimate the lifetime of the components [12, 13].

The present study is an attempt to address the issues lead to determine HEP evaluation using fuzzy relation for max–min composition by considering the inter-dependent relationship between the performance shaping factors (PSFs). This approach is discussed through a case study of power grid system.

The structure of the paper is as follows: In section 2, the work related to human error probability is discussed. In section 3, the necessary definition of fuzzy sets and basics of human error probability are presented. A schematic representation for the proposed approach for fuzzy relation that lead to human error probability and a case study is discussed in section 4 and 5 respectively. The results and discussion is presented in section 6. Section 7 provides conclusion.

# 2. Related Work

An approach for HEP evaluation by considering the dependency between the influencing factors using Cognitive Reliability and Error Analysis Method (CREAM) and human reliability is discussed through the analysis of power system switching operation. The construction of PIFs is based on dependency level. Bayesian Network and fuzzy theory are used and compared to CREAM extension method to evaluate the human reliability in [3]. The human error evaluation in marine accidents by post-hoc analysis was performed using Technique for Human Error Rate Prediction (THERP) model by the results of event tree analysis discussed in [4]. The principle issues in HRA such as model theoretical basis, PSF and their quantification are discussed in [14]. THERP, A Technique for Human Event Analysis (ATHEANA), CREAM, Standardized Plant Analysis Risk Human Reliability Assessment (SPAR-H) and Success Likelihood Index Method using Multi-Attribute Utility Decomposition (SLIM-MAUD) are the most commonly used HRA approaches in nuclear power plants. The strength and weaknesses of each method are discussed in [15].

Analysis of an aircraft accident (occurred in Japan) was done by HRA method, THERP and the risk achievement worth is an important factor used to quantify the process of human reliability analysis [8]. The human reliability framework for complicated space mission operation process, gives the concept of Meta-operation developed by phased mission system and human cognition reliability model [16]. The human reliability of power system, human error causal framework and the Performance Influencing Factors (PIFs) are used to evaluate the human reliability using the Bayesian network probabilistic inference model. This technique has been applied to integrate the three human factors such as organizational factors, situational factors and individual factors to quantitatively measure the human reliability of power system in [17, 18]. Reliability of the human operator in the Man – Machine – System is discussed in [19]. Improving the likelihood of human actions in railway transportation system using failure mode effects and criticality analysis (FMEA), HRA are discussed in [20]. A quantitative technique considering human as the component of system for risk assessment to study its impact on system safety for railway and advanced driver assistance systems for automobiles is discussed in [2, 21].

A method for predicting HEP by integrating PSFs and Bayesian networks theory is discussed in [22, 23]. Generally, probabilistic concepts are used as background to model the Human Reliability Assessment. However, fuzzy logic approach can better model the human performance for complex and uncertain process [12]**.** A fuzzy-based decision support system for the analysis of human reliability in operation, maintenance and inspection activities in industrial and production processes, where the human error may have a great impact on safety and on the environment is discussed with a unit of a Petrobras oil refinery (Brazilian Oil Company) in [24]. HRA method based on human cognitive process model is proposed to analyze the human reliability of different kinds of behaviour quantitatively discussed in [25]**.** Analyze the impact of human factors on power system reliability is discussed and firstly, summarize the current situation of human factors in power system. Human factor affects the power system reliability discussed in two ways such as: imperfect maintenance caused by human errors, and impact of human factors on emergency dispatch operation and power system cascading failure in [26].

Fuzzy operations and fuzzy failure probability are used to describe the fuzzy fault tree method to analyze the human reliability. Instead of using fault tree operations, the fuzzy operations are applied in fault tree analysis to quantify the fuzzy reliability [13, 27]. Number of accidents occurs during every year in chemical industries based on the component. To avoid this situation, fault tree analysis is used by considering the common cause failure and their dependencies between the components. The approach is discussed through the chemical storage tank in the chemical plant [11].

# 3. Basic Concepts of Fuzzy Sets

In this section, the concepts of fuzzy sets, fuzzy relation, fuzzy composition and PIFs are explained.

**Membership Function of Fuzzy Sets**

Fuzzy sets were introduced by Lotfi A. Zadeh in 1965 as an extension of classical set [28, 29]. Every element in a fuzzy set is associated with a membership function. Let $X$ be a non-empty set and a fuzzy set $A$ in the universe of discourse $X$ is qualified by its membership function $\mu_A$ defined as,

$$\mu_A : X \to [0,1] \text{ defined by } \mu_A(x) \in [0,1]$$

The fuzzy set $A$ in $X$ is denoted by $\tilde{A}$. The membership function maps every element in $X$ into the real valued interval $[0,1]$. Fuzzy set is a "vague boundary set" comparing with crisp set. Thus, the elements of a fuzzy set are discrete and finite mapped to a universe of membership values using a function-theoretic form

$$\tilde{A} = \left\{ \frac{\mu_{\tilde{A}}(x)}{x_1} + \frac{\mu_{\tilde{A}}(x)}{x_2} + \cdots \right\} = \left\{ \sum_i \frac{\mu_{\tilde{A}}(x)}{x_i} \right\}$$

If the universe of discourse $X$ is continuous or infinite, the fuzzy set $\tilde{A}$ is defined as

$$\tilde{A} = \left\{ \int \frac{\mu_{\tilde{A}}(x)}{x_i} \right\}$$

The term $\mu_i / x_i\, , for\ all\ i = 1,2,\ldots,n$ indicates the grade of membership values of fuzzy set $\tilde{A}$ in the universe of discourse $X$.That is, the horizontal bar is not a quotient but rather a delimiter and the numerators in each term is the grade of membership value in fuzzy set $\tilde{A}$ associated with the element $x$ in the universe $X$. Consequently, the summation symbol does not represent the algebraic sum but rather the collection/aggregation of each element. Thus, the symbol '+' sign is not the algebraic ''addition'' but collection/aggregation operator. Also, the integral sign is not an algebraic integral but a continuous function-theoretic form which represents an aggregation operator for continuous variables.

**Fuzzy Operations**

The fuzzy operations for union, intersection and complement functions are defined by set theoretic representations of any two fuzzy sets $\tilde{A}\ and\ \widetilde{B}$ in the universe of discourse as follows:

$$\mu_{\tilde{A}\cup\tilde{B}} = max\{\mu_{\tilde{A}}(x),\ \mu_{\tilde{B}}(x)\} = \mu_{\tilde{A}}(x) \vee \mu_{\tilde{B}}(x)$$
$$\mu_{\tilde{A}\cap\tilde{B}} = min\{\mu_{\tilde{A}}(x),\ \mu_{\tilde{B}}(x)\} = \mu_{\tilde{A}}(x) \wedge \mu_{\tilde{B}}(x)$$
$$\mu_{\bar{\tilde{A}}}(x) = 1 - \mu_A(x)$$

**Fuzzy Relations**

A fuzzy relation $R$ is a membership function defined on any two fuzzy sets $\tilde{A}\ and\ \tilde{B}$ over the Cartesian space $X \times Y$ given by

$$\mu_R(x,y): \tilde{A} \times \tilde{B} \to [0,1]$$

Defined by $R = \{((x,y),\ \mu_R(x,y)/\mu_R(x,y) \geq 0,\ x \in \tilde{A},\ y \in \tilde{B}\}$.

Here, the fuzzy relation $R$ is an ordered pair of elements $(x,y)$ representing the fuzzy sets $\tilde{A}\ and\ \tilde{B}$ respectively. Similarly, the fuzzy relation of union, intersection and complement over any two fuzzy relations $R\ and\ S$is given by

$$\mu_{R\cup S} = max\{\mu_R(x), \mu_S(x)\} = \mu_R(x) \vee \mu_S(x)$$
$$\mu_{R\cap S} = min\{\mu_R(x), \mu_S(x)\} = \mu_R(x) \wedge \mu_S(x)$$
$$\mu_{\bar{R}}(x) = 1 - \mu_R(x)$$

Generally, the fuzzy relation can be assumed to be a fuzzy restriction to the Cartesian product $X \times Y$. Therefore, the fuzzy relation $R \subseteq X \times Y$ .

**Fuzzy Max-Min Compositions**

Let $R\ and\ S$ be any two fuzzy relations of an ordered pairs $(x,y)$ and $(y,z)$ over the fuzzy sets $\tilde{A}\ and\ \tilde{B},\ and\ \tilde{B}\ and\ \tilde{C}$ respectively. Then, the grade of membership for the fuzzy relation $\mu_R(x,y)\ and\ \mu_S(y,z)$forms a composition $T$ from the fuzzy sets $\tilde{A}\ and\ \tilde{C}$ as

$$T = R \circ S$$
$$\mu_T(x,z) = \bigvee_{y\in\tilde{B}} (\ \mu_R(x,y) \wedge \mu_S(y,z))$$

**Performance Influencing Factor**

An initial stage of HRA is to determine a set of human factors related to operation performance. PIFs are used to represent the situational context and causes affecting human performance in different systems. Generally, it is very difficult to integrate all PIFs since human reliability is influenced by a large number of different factors. The selection of PIFs is described as follows: each PIF's is independent, measurable and evaluable; the PIFs are dependent of each other so it is necessary to make PIFs selection in such a way to avoid the possibility of double counting; the PIFs with major impact should be covered as much as possible.

# 4. Proposed Approach

Human error mechanism is an important factor in HRA. Generally, the PIFs are causing human error. There are many real life uncertainties involved in the implementation to evaluate the human error. The present study of this paper explains the HEP evaluation by fuzzy relation using max-min composition. The fuzzy relation is used capture the uncertainties between the PIFs. This proposed approach has been diagrammatically shown in Fig. 1.

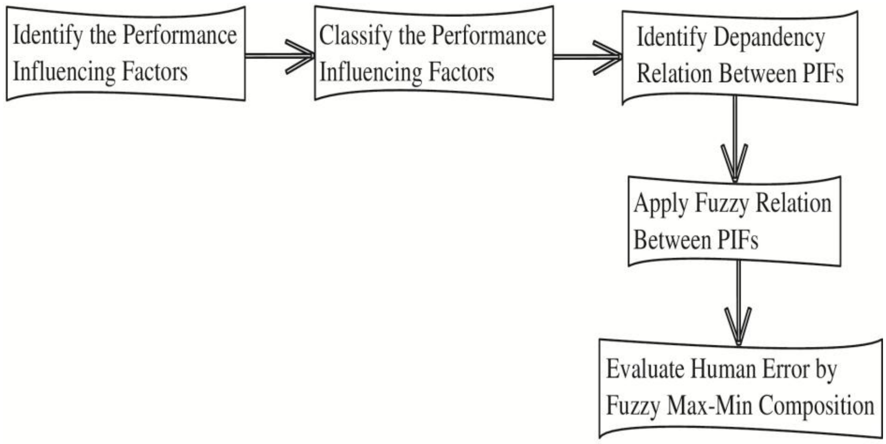


Figure 1: A Schematic Representation for HEP Evaluation using Fuzzy Relation

# 5. Case Study

The case study for describing a casual framework of HEP evaluation in power grid system was taken from [17].

**Problem Description**

The influencing factors which leads to the HEP of power grid system is classified in the following three categories namely organizational factors (OF), situational factors (SF) and individual factors (IF). Management activities and organizational processes, organizational structure, task management, procedure quality, resource allocation and training quality are classified under organizational factors.

Work load (W), available time (A), work environment (W), equipment condition and quality of man-machine interface are classified under situational factors. Also, Individual factors are operator's physiological state, skills and experience level (S).

The impact on human error in power grid system can be related as follows: the organizational factor leads to individual factors in two ways. The organizational factors affect the situational factors which cause human reliability. It can also cause a direct impact on individual factors to raise the possibility of operator error.

Similarly, the situational factors are determined by context and environmental conditions during the operation process. The classification of each PIFs with their detailed description [17] is given in Table 1.

Table 1: List of all PIFs and their description

| PIFs | Explanations |
|---|---|
| Task Scheduling (T) | the type, importance and complexity of tasks |
| Operational Procedure (O) | the logical structure, detail, complexity, completeness and terminology definition of the operational procedure |
| Training Quality (Q) | training methods, professional standards and evaluation |
| Personnel Arrangement (R) | the number, professionalism, qualification and status of personnel and quality of cooperation |
| Available Time (A) | the available time for the operator to complete the work |
| Work Load (W) | work intensity, complexity and the number of targets to be completed at the same time and consequence of failure |
| Work Environment (E) | the temperature, light, nose and external disturbance of the workplace |
| Equipment Operability (I) | the stability, recognizability, usability, accessibility and so on the equipment |
| Pressure (P) | stress caused by work load and time limitation |
| Attention (F) | the operator's attention level to current task |
| Skills and Experience (S) | operator's professionalism, knowledge, skills and experience level |

The human error casual frameworks for PIFs are diagrammatically shown in Fig. 2.

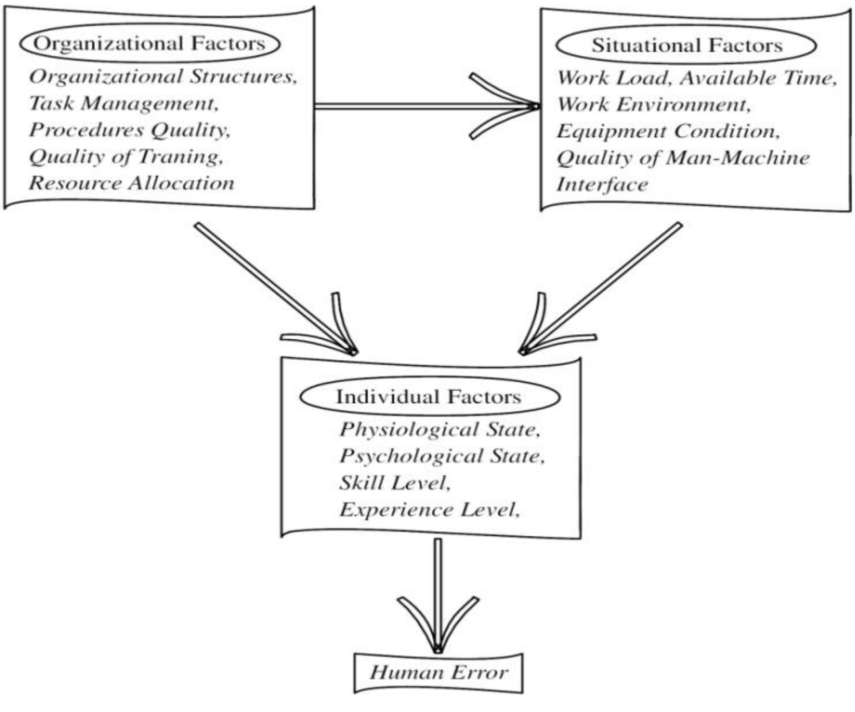


Figure 2: Classification of all PIFs for HEP Evaluation

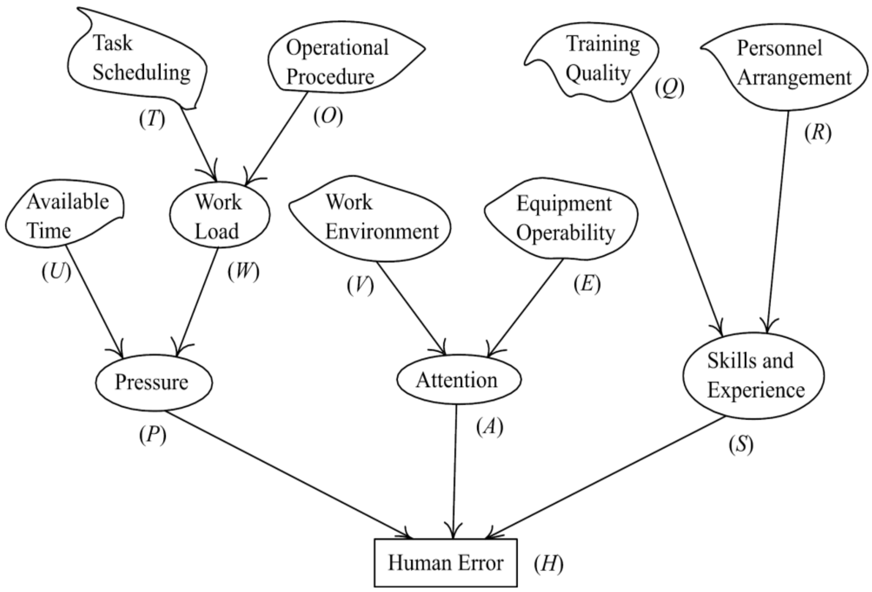

Figure 3: Classification of all PIFs of the Power Grid System

Fig. 3 shows, the organizational factors task scheduling and operational procedure causes an indirect impact on the individual factor pressure, through the situational factor work load. Also the organizational factors training quality and personnel arrangement affects a direct impact on the individual factor skill and experience. The situational factors available time, work load and work environment, equipment operability causes an impact on individual factors pressure and attention respectively. Finally the individual factors pressure, attention, skill and experience lead to the human error of the power grid system.

**Fuzzy Relation to Lead Human Error Probability**

In this case study, the nature of all PIFs is in linguistic variables. The impact of PIF pressure is obtained as follows:

1. When the task scheduling has the linguistic variables such as unreasonable (UR), acceptable (AC) and reasonable (RE); then we have the relational matrix between the PIFs from operational procedure to work load.
2. When the available time has the linguistic variables such as inadequate (IAD), acceptable (AC) and adequate (AD); then we have the relational matrix between the PIFs from work load to pressure.
3. Using above two cases, we define the fuzzy relation between the PIFs from operational procedure to pressure which lead to direct impact on human error of the power grid system in which the pressure depends on the other primary PIFs such as attention, skill and experience.

Therefore, 9 fuzzy relations exists using fuzzy max-min composition rule between PIFs from operational procedure to work load. This max-min composition rule yields 9 fuzzy relation between PIFs from operational procedure to work load is shown in Fig. 4.

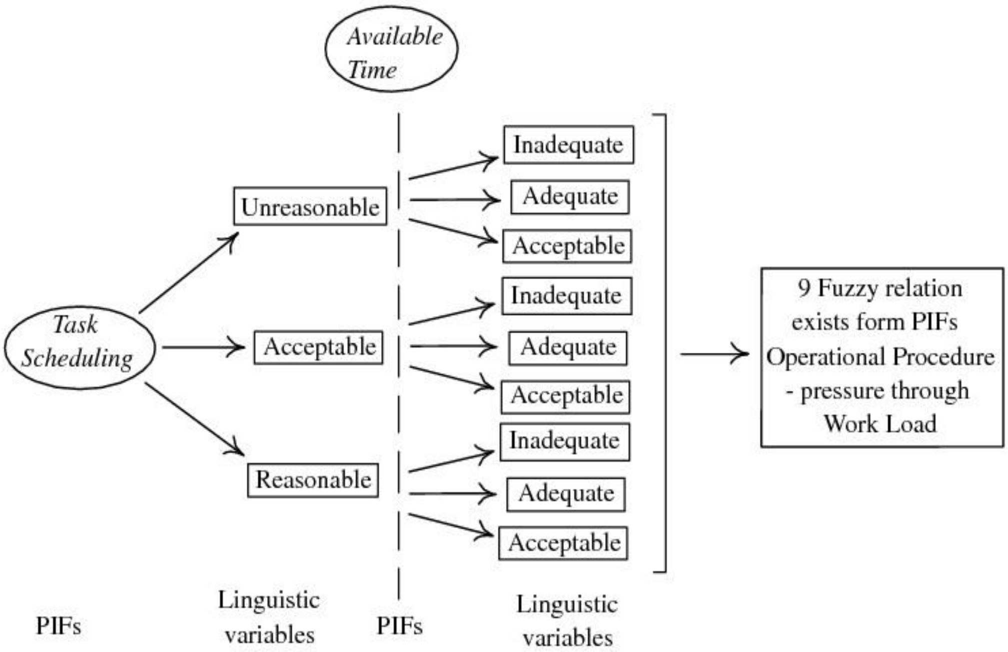


Figure 4: Fuzzy Composition between PIFs from Operational Procedure to Pressure through Workload

Thus, in all 9 fuzzy rules, the linguistic variable for operational procedure (linguistic variables: inappropriate (IA), acceptable (AC), appropriate (AP)) to work load (linguistic variable: low (L), moderate (M), high (H)) that depends on task scheduling. Also, the linguistic variable for work load (linguistic variable: low (L), moderate (M), high (H)) to pressure (linguistic variable: low (L), moderate (M), high (H)) that depends on available time.

The dependency relations between the PIFs (See Fig. 4) using max – min composition, 9 fuzzy relations are defined in the following.

1. If task scheduling is unreasonable and available time is inadequate then a fuzzy composition exists from PIFs operational procedure to pressure.

$$\begin{array}{c} \\ IA \\ AC \\ AP \end{array}\!\!\begin{array}{c} \begin{array}{ccc} L & M & H \end{array} \\ \begin{bmatrix} 0.01 & 0.09 & 0.9 \\ 0.05 & 0.15 & 0.8 \\ 0.2 & 0.6 & 0.2 \end{bmatrix} \end{array} \circ \begin{array}{c} \\ L \\ M \\ H \end{array}\!\!\begin{array}{c} \begin{array}{ccc} L & M & H \end{array} \\ \begin{bmatrix} 0.2 & 0.5 & 0.3 \\ 0.05 & 0.15 & 0.8 \\ 0.01 & 0.09 & 0.9 \end{bmatrix} \end{array} = \begin{array}{c} \\ IN \\ AC \\ AP \end{array}\!\!\begin{array}{c} \begin{array}{ccc} L & M & H \end{array} \\ \begin{bmatrix} 0.09 & 0.15 & 0.3 \\ 0.15 & 0.15 & 0.3 \\ 0.2 & 0.2 & 0.3 \end{bmatrix} \end{array}$$

2. If task scheduling is unreasonable and available time is acceptable then a fuzzy composition exists from PIFs operational procedure to pressure.

$$\begin{array}{c} \\ IA \\ AC \\ AP \end{array}\!\!\begin{array}{c} \begin{array}{ccc} L & M & H \end{array} \\ \begin{bmatrix} 0.01 & 0.09 & 0.9 \\ 0.05 & 0.15 & 0.8 \\ 0.2 & 0.6 & 0.2 \end{bmatrix} \end{array} \circ \begin{array}{c} \\ L \\ M \\ H \end{array}\!\!\begin{array}{c} \begin{array}{ccc} L & M & H \end{array} \\ \begin{bmatrix} 0.6 & 0.3 & 0.1 \\ 0.1 & 0.7 & 0.2 \\ 0.1 & 0.3 & 0.6 \end{bmatrix} \end{array} = \begin{array}{c} \\ IN \\ AC \\ AP \end{array}\!\!\begin{array}{c} \begin{array}{ccc} L & M & H \end{array} \\ \begin{bmatrix} 0.1 & 0.3 & 0.1 \\ 0.15 & 0.3 & 0.1 \\ 0.2 & 0.3 & 0.2 \end{bmatrix} \end{array}$$

3. If task scheduling is unreasonable and available time is adequate then a fuzzy composition exists from PIFs operational procedure to pressure.

$$\begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} IA \\ AC \\ AP \end{matrix} & \begin{bmatrix} 0.01 & 0.09 & 0.9 \\ 0.05 & 0.15 & 0.8 \\ 0.2 & 0.6 & 0.2 \end{bmatrix} \end{array} \circ \begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} L \\ M \\ H \end{matrix} & \begin{bmatrix} 0.9 & 0.09 & 0.01 \\ 0.8 & 0.15 & 0.05 \\ 0.3 & 0.5 & 0.2 \end{bmatrix} \end{array} = \begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} IN \\ AC \\ AP \end{matrix} & \begin{bmatrix} 0.8 & 0.09 & 0.01 \\ 0.8 & 0.09 & 0.05 \\ 0.3 & 0.2 & 0.2 \end{bmatrix} \end{array}$$

4. If task scheduling is acceptable and available time is inadequate then a fuzzy composition exists from PIFs operational procedure to pressure.

$$\begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} IA \\ AC \\ AP \end{matrix} & \begin{bmatrix} 0.05 & 0.15 & 0.8 \\ 0.1 & 0.8 & 0.1 \\ 0.8 & 0.15 & 0.05 \end{bmatrix} \end{array} \circ \begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} L \\ M \\ H \end{matrix} & \begin{bmatrix} 0.2 & 0.5 & 0.3 \\ 0.05 & 0.15 & 0.8 \\ 0.01 & 0.09 & 0.9 \end{bmatrix} \end{array} = \begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} IN \\ AC \\ AP \end{matrix} & \begin{bmatrix} 0.15 & 0.15 & 0.3 \\ 0.1 & 0.1 & 0.3 \\ 0.05 & 0.09 & 0.8 \end{bmatrix} \end{array}$$

5. If task scheduling is acceptable and available time is acceptable then a fuzzy composition exists from PIFs operational procedure to pressure.

$$\begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} IA \\ AC \\ AP \end{matrix} & \begin{bmatrix} 0.05 & 0.15 & 0.8 \\ 0.1 & 0.8 & 0.1 \\ 0.8 & 0.15 & 0.05 \end{bmatrix} \end{array} \circ \begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} L \\ M \\ H \end{matrix} & \begin{bmatrix} 0.6 & 0.3 & 0.1 \\ 0.1 & 0.7 & 0.2 \\ 0.1 & 0.3 & 0.6 \end{bmatrix} \end{array} = \begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} IN \\ AC \\ AP \end{matrix} & \begin{bmatrix} 0.15 & 0.3 & 0.1 \\ 0.1 & 0.3 & 0.1 \\ 0.1 & 0.3 & 0.2 \end{bmatrix} \end{array}$$

6. If task scheduling is acceptable and available time is adequate then a fuzzy composition exists from PIFs operational procedure to pressure.

$$\begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} IA \\ AC \\ AP \end{matrix} & \begin{bmatrix} 0.05 & 0.15 & 0.9 \\ 0.1 & 0.8 & 0.8 \\ 0.8 & 0.15 & 0.2 \end{bmatrix} \end{array} \circ \begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} L \\ M \\ H \end{matrix} & \begin{bmatrix} 0.9 & 0.09 & 0.01 \\ 0.8 & 0.15 & 0.05 \\ 0.3 & 0.5 & 0.2 \end{bmatrix} \end{array} = \begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} IN \\ AC \\ AP \end{matrix} & \begin{bmatrix} 0.8 & 0.09 & 0.05 \\ 0.3 & 0.1 & 0.1 \\ 0.3 & 0.15 & 0.15 \end{bmatrix} \end{array}$$

7. If task scheduling is reasonable and available time is inadequate then a fuzzy composition exists from PIFs operational procedure to pressure.

$$\begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} IA \\ AC \\ AP \end{matrix} & \begin{bmatrix} 0.2 & 0.6 & 0.2 \\ 0.8 & 0.15 & 0.05 \\ 0.9 & 0.09 & 0.01 \end{bmatrix} \end{array} \circ \begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} L \\ M \\ H \end{matrix} & \begin{bmatrix} 0.2 & 0.5 & 0.3 \\ 0.05 & 0.15 & 0.8 \\ 0.01 & 0.09 & 0.9 \end{bmatrix} \end{array} = \begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} IN \\ AC \\ AP \end{matrix} & \begin{bmatrix} 0.2 & 0.2 & 0.3 \\ 0.05 & 0.09 & 0.8 \\ 0.01 & 0.09 & 0.8 \end{bmatrix} \end{array}$$

8. If task scheduling is reasonable and available time is acceptable then a fuzzy composition exists from PIFs operational procedure to pressure.

$$\begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} IA \\ AC \\ AP \end{matrix} & \begin{bmatrix} 0.2 & 0.6 & 0.2 \\ 0.8 & 0.15 & 0.05 \\ 0.9 & 0.09 & 0.01 \end{bmatrix} \end{array} \circ \begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} L \\ M \\ H \end{matrix} & \begin{bmatrix} 0.6 & 0.3 & 0.1 \\ 0.1 & 0.7 & 0.2 \\ 0.1 & 0.3 & 0.6 \end{bmatrix} \end{array} = \begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} IN \\ AC \\ AP \end{matrix} & \begin{bmatrix} 0.2 & 0.3 & 0.2 \\ 0.1 & 0.3 & 0.2 \\ 0.1 & 0.3 & 0.2 \end{bmatrix} \end{array}$$

9. If task scheduling is reasonable and available time is adequate then a fuzzy composition exists from PIFs operational procedure to pressure.

$$\begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} IA \\ AC \\ AP \end{matrix} & \begin{bmatrix} 0.2 & 0.6 & 0.2 \\ 0.8 & 0.15 & 0.05 \\ 0.9 & 0.09 & 0.01 \end{bmatrix} \end{array} \circ \begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} L \\ M \\ H \end{matrix} & \begin{bmatrix} 0.9 & 0.09 & 0.01 \\ 0.8 & 0.15 & 0.05 \\ 0.3 & 0.5 & 0.2 \end{bmatrix} \end{array} = \begin{array}{cc} & \begin{matrix} L & M & H \end{matrix} \\ \begin{matrix} IN \\ AC \\ AP \end{matrix} & \begin{bmatrix} 03 & 0.2 & 0.2 \\ 0.3 & 0.15 & 0.15 \\ 0.3 & 0.15 & 0.09 \end{bmatrix} \end{array}$$

Thus, the fuzzy relation is attained between from PIFs operational procedure to pressure.

# 10. Results and Discussion

In this case study we observe, when the task scheduling is unreasonable (see the fuzzy relation cases 1, 2, 3), the possibility of pressure is high (0.3) for available time being inadequate; moderate (0.3) for available time being acceptable; and low (0.3, 0.8) when the available time is adequate. Also, when the task scheduling is acceptable; the possibility of pressure is high (0.3, 0.8) for available time being inadequate; medium (0.3) for available time is acceptable; and low (0.3, 0.8) when available time is adequate. Similarly, the possibility of pressure varies from high (0.3, 0.8), medium (0.3) and low (0.3); when the task scheduling being acceptable with available time being inadequate, acceptable and adequate respectively. The advantage of fuzzy relation used in this case study is the max-min composition rule yields the values to integrate and makes it easy to find the effect of pressure.

# 11. Conclusion

The present study of this paper describes the fuzzy relation between the PIFs. This max-min composition rule yields fuzzy relation between PIFs from operational procedure to work load. Fuzzy relation is a well implemented technique to adopt the inter-relations between these linguistic values that lead to attain HEP. As a future work, this novel approach can be extended to model the complex system for evaluating HEP by considering all the dependency between operators.

# Acknowledgement

The authors thank SSN Management and Principal for their necessary support to carry out this research work.

# References

[1] Pedro A., Baziuk S., Selva R., Nunez Mc Leod J., Fuzzy Human Reliability Analysis: Applications and Contributions Review, Advances in Fuzzy Systems, Hindawi Publishing Corporation (2016), 1-9.

[2] Rangra S., Sallak M., Schon W., Vanderhaegen F., On the study of human reliability in transportation systems of systems, In IEEE 10th System of Systems Engineering Conference (SoSE) (2015), 208-213.

[3] Bao Y., Tang J., Lu H., Wang Y., Guo C., Yu Z., Jiang Y., Analysis of human reliability in power system switching operation considering dependency of operators, In IEEE Conference on PES Asia-Pacific Power and Energy Engineering (APPEEC) (2013), 1-6.

[4] Atsushi H., Chihiro N., Nobuo M., A study on application to marine accident of human reliability analysis method, IEEE International conference on informatics, Electronics & vision (ICIEV), (2015).

[5] Chen Z., Zhang W., Dong D., Lu K., An extended CREAM by modified algorithm to human reliability quantification in marine engineering, IEEE Reliability and Maintainability Symposium (RAMS) (2017), 1-5.

[6] Brall A., Human reliability issues in medical care - a customer viewpoint, IEEE Reliability and Maintainability Symposium, RAMS'06 (2006), 46-50.

[7] Rajabalinejad M., Martinetti A., Van Dongen L.A.M., Operation, safety and human: Critical factors for the success of railway transportation, 11th IEEE Conference System of Systems Engineering (SoSE), (2016).

[8] Nobuo M., Atsushi H., Kensuke H., An example of an accident analysis of aircrafts based on human reliability Analysis Method, IEEE International Conference on Informatics, Electronics & Vision (ICIEV) (2015), 1-5.

[9] Auob M., Hossein M., Maryam Z., Fuzzy-based Prioritization of Health, Safety, and Environmental Risks: The Case of a Large Gas Refinery, Iranian Journal of Health, Safety & Environment 4 (1) (2016), 641-653.

[10] Diana L.D., Tailoring a Human Reliability Analysis to Industry Needs, Annual Reliability and Maintainability Symposium (RAMS), (2016).

[11] Mohammad Y., Farzaneh N., Mahnaz N., Failure probability analysis by employing fuzzy fault tree analysis, International Journal of System Assurance Engineering and Management (2017), 1-17.

[12] Selva Rivera S., Pedro A.B., Nunez Mc Leod J., Fuzzy Uncertainties in Human Reliability Analysis, Proceedings of the World Congress on Engineering, (2011).

[13] Sanjay K.T., Pandey D., Reena T., Fuzzy set theoretic approach to fault tree analysis, International Journal of Engineering, Science and Technology 2 (5) (2010), 276-283.

[14] Pedro A.B., Jorge N.M.L., Romina C., Selva S.R., Principal Issues in Human Reliability Analysis, Proceedings of the World Congress on Engineering, (2015).

[15] Julwan H.P., Sony Tjahyani D.T., Human reliability analysis in nuclear power plants, Proceeding Seminar National Technology Energy Nuclear (2016), 409-415.

[16] Yang Y., Liu W., Kang R., Zheng W., The model framework of human reliability for complicated spaceflight mission, In Proceedings of the IEEE Prognostics and System Health Management, (2012).

[17] Junxi T., Yingkai B., Licheng W., Haibo L., Yue W., Chuangxin G., Jia L., Bin Z., A Bayesian network approach for human reliability analysis of power system, IEEE PES Asia-Pacific Conference on Power and Energy Engineering (APPEEC), (2013).

[18] Bao Y., Guo J., Tang J., Li Z., Pang S., Guo C., Analysis of power system operation reliability incorporating human errors, In 17th IEEE International Conference on Electrical Machines and Systems (ICEMS) (2014), 1052-1056.

[19] Marie H., Sona S., Reliability analysis of the human operator, 13th IEEE International Carpathian Control Conference (ICCC) (2012), 209-214.

[20] De F.F., Antonella P., Methodological approach for performing human reliability and error analysis in railway transportation system, International Journal of Engineering and Technology 3 (5) (2011), 341-353.

[21] Balbir S.D., Human Reliability and Error in Transportation Systems, Springer Science & Business Media, Canada, (2007).

[22] Mu L., Xiao B.P., Xue W.K., Yuan Z., The prediction of human error probability based on Bayesian networks in the process of task, IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), (2015), 145-149.

[23] Eduardo C., Gas and Oil Reliability Engineering: Modeling and Analysis, Gulf Professional Publishing is an imprint of Elsevier, Waltham, USA, (2013).

[24] Szwarcman D.M., Domech J., Tanscheit R., Vellasco M., Pacheco M., Ribeiro N.P., A Fuzzy System for the Assessment of Human Reliability, IFSA-EUSFLAT (2009), 1102-1107.

[25] Huimin Y., Wei Z., A human reliability analysis method based on cognitive process model for risk assessment, IEEE International Conference on Intelligent Rail Transportation (ICIRT) (2016), 418 – 424.

[26] Yingkai B., Chuangxin G., Jinjiang Z., Jiaxin W., Suhong P., Zhiping Z., Impact analysis of human factors on power system

operation reliability, Journal of Modern Power Systems and Clean Energy (2016), 1-13.

[27] Hany S., Ehab S., Eisawy E.A., Human factors reliability analysis using fuzzy fault tree, International Journal of Engineering and Innovative Technology (IJEIT) 4 (10) (2015).

[28] Lee, Kwang Hyung, First course on fuzzy theory and applications, Springer Science & Business Media, (2006).

[29] Ross, Timothy J., Fuzzy Logic with Engineering Applications. John Wiley & Sons, (2009).