Human Performance using Fuzzy Inherent Safety Tool (HuP-FiST)

By

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CERTIFICATION OF APPROVAL

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Approved by,

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NOOR AIN BINTI AB KADIR

ABSTRACT

Human factor (HF) is an important concern for most industry especially for the chemical and petrochemical industry. This is because; many accidents in such industry are contributed by human error. It can be proved that the incident rate due to HF had increased from time to time. There are findings based on survey show that 64% of total incidents are mainly due to human error. Thus, a study regarding human factor, method to quantitatively estimate the contribution of HF and how to reduce it using Inherent Safety (IS) principle need to be developed.

Therefore, a new tool which is simple and cost optimal approach had been chosen to satisfy the need. This method is referred to Inherent Safety Tool (IST) using fuzzy analytical hierarchy process (FAHP) theory in index computation; a type of trapezoidal fuzzy number (TFN) ranges to identify fuzzy evaluating vector. The tool can be simplified as Human Performance using Fuzzy Inherent Safety Tool or HuP-FiST. This tool is aim to support decision making and control human error in order to improve human performance while working. The application of pair-wise comparison matrix and TFN could be used for human error occurrence and mitigate the end results of HF. Lastly, this study also used the case study process to identify the TFN and end result for concept validation.

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ABBREVIATIONS AND NOMENCLATURES

Abbreviations

AHP	Analytical Hierarchy Process
CI	Consistency Index
CR	Consistency Ratio
FAHP	Fuzzy Analytical Hierarchy Process
HE	Human Error
HF	Human Factor
HI	Hazard Identification
HuP-FiST	Human Performance using Inherent Safety Tool
IS	Inherent Safety
PHA	Process Hazard Analysis
RI	Random Index
TFN	Trapezoidal Fuzzy Number
WBGT	Wet Bulb Globe Temperature

Nomenclatures

9-point scale	Used for the FAHP to represent the pair-wise comparison
AHP	Multi criteria decision method which includes both qualitative and quantitative aspect
Crisp value	Defuzzification of fuzzy number into exact value
Geometric mean method	Method to converting the element of pair-wise comparison
Inherent Safety	Primary prevention risk management
Linguistic variable	Provide value in words or sentences in a natural language

CHAPTER 1

INTRODUCTION

1.1 Project Background

Human factor or human error is a common issue that regularly occurs at the industry. There are many incidents had been recorded due to process failures such as Bhopal Tragedy in 1984, Piper Alpha disaster in 1988, Texas City Refinery fire in 1994 and etc. In fact, all of these accidents have human errors either direct or indirect cause (Kariuki, 2007). Based on the survey conducted by Technische Universitat Berlin (TUB) 2007, 64% of total incidents are due to human failure as a primary cause (Kariuki, 2007). This also can be proved by Datuk Nur Iskandar Abdul Samad (2012) who stated that 80% accidents in PETRONAS are due to human error. Thus, HF that contributes to human error is important to be identified and mitigated.

Inherent safety which is known as primary prevention (Kletz, 2009) is a proactive approach for loss prevention and risk management (Khan, 2005). Inherent safety not only a proactive approach, it also very cost effective and simple method to identify and mitigate the hazards. By using this method, hazard can be eliminated rather than being managed by high technology equipment and procedures.

1.2 Problem Statement

Research shows that, majority of the accidents is caused by human failure either through direct action or poor design (Kariuki, 2007). In addition, complex working environment, organization factor, information and etc also contribute to this aspect where it should be minimized and eliminated. There are current available tool had been developed but currently most of it just focuses on process route or chemicals failure. There are also minor tools been developed to enhance human error but it just focus to probability of the consequences. Therefore, to identify and reduce the human error efficiently, a simple, sensitive and cost optimal approach is necessary.

1.3 Project Objectives

The objectives of this project are as following:-

1. To develop tool for identification of human error
2. To identify and prioritize the control measures based on IS approach

1.4 Scope of Study

The scopes of study for this project are firstly scope of the common human factors. The factors are work/job design, task environment, workers/operator characteristics, information, human system interface and workplace design. Secondly, focus on the chosen tool which is Human Performance - Fuzzy Inherent Safety Tool (HuP-FiST). This tool is using fuzzy analytical hierarchy process (FAHP) theory in index computation; a type of trapezoidal fuzzy number (TFN) ranges to identify fuzzy evaluating vector. Lastly the evaluation of the develop tools based on published case study.

CHAPTER 2
LITERATURE REVIEW

2.1 Human Error (HE) & Human Factor (HF)

As stated earlier, human error is a major cause of undesired events in process industries. For example, if the design and layout of procedures do not clearly indicated, it can increase the potential error which it should be eliminated or substituted to others (Kletz, 2009). Other example of human factor is the shift and overtime. Optimum shift rotation schedule is required in operating system to avoid fatigue. As a result, it can help operators or personnel run the plant in safer way.

Therefore, human factor analyses need to be done in order to ensure that all HF related to hazard have been analyzed, studied and integrated. This approach is conducted to make sure that hazard of human error can be eliminated or minimized physically or mentally (Kariuki, 2007).

Based on researches, there are several human factors can be considered but only six factors had been chosen. This is based on several researches of previous incidents which show the common human error contribution. The HF had been simplified in Table 1 below.

Table 1: Human Factor areas (CCPS, 1994 & Kariuki, 2007)

MAIN FACTOR	SUB FACTOR
1.0 Work/Job Design (JD)	1.1 Work Nature 1.2 Work Intensity 1.3 Work Schedules 1.4 Manual Handling
2.0 Task Environment (TE)	2.1 Thermal Condition (Temperature) 2.2 Thermal Condition (Humidity) 2.3 Airflow Velocity 2.4 Heat Radiation Intensity 2.5 Lightning 2.6 Noise
3.0 Worker/Operator Characteristics (OC)	3.1 Experience 3.2 Training 3.3 Atmospheric Condition/PPE 3.4 Physical Condition
4.0 Information (INF)	4.1 Procedures 4.2 Communication 4.3 Labels and signs
5.0 Human System Interface (HSI)	5.1 Design of Control Panels 5.2 Displays
6.0 Workplace Design (WD)	6.1 Facility Layout 6.2 Accessibility

2.2 Available Tools to Improve Human Factor (HF)

Due to a lot of industrial accidents happen all around the world such as Bhopal Tragedy (1984), Piper Alpha disaster (1988), Texas City Refinery fire (1994) and etc, there are many researches carried out on the factor that contribute to the issues. There are also tools had been develop in order to minimize or improve human error. Certain tools commercial to be use in our region and industries, but some of them is difficult or too complicated. On the other hand, some of them just focus on process or chemical reaction only. In order to make a good decision on which approaches to choose, the pro and cons of each type of available tools is listed and compared to identify which tool is suitable and cost effective to improve human performance.

2.2.1 Current Hazard Identification (HI) Tools

2.2.1.1 Analytical Hierarchy Process (AHP)

AHP is one method to improve human error and accidents. AHP developed by Saaty (1980) is multi criteria decision method which includes both qualitative and quantitative aspect. The result obtain from this method are objectives and realistic (Saaty, 1980) which is based on judgment and user's experience. AHP by-product is an index of consistency which gives information on the severity of the numerical and transitive steadiness violation. For example if the consistency ratio (CR) is above 0.1, the person making the judgment should seek additional information, re-examine the data used in constructing the scale and then make new judgment (Saaty, 1980). There are three parts in this method which are; a preliminary part, an expert judgment part and a calibration part (Park, 2007). Nevertheless, this method is not an absolute standard as it can be changed according to the circumstances.

2.2.1.2 Process Hazard Analysis (PHA)

Another approach to improve human error is using process hazard analysis (PHA). This method is systematic approach to identify hazard and critical accidents scenarios. PHA can eliminate and control process hazard if it is done comprehensively during the life cycle of the plant (Kariuki, 2007). It also elaborates how the technical failure, human failure as well as external event lead to undesired events. In this case, it allowed user to identify which barriers that need to contain propagation of unwanted event (Kariuki, 2007). However, a PHA method does not give human failure the weight it deserves as major contributor to unwanted events is complex action includes many others factor.

2.2.2 Available Tool using IS Approach

2.2.2.1 Inherent Safety Principles and Guidewords

Both hazard and risk is common factors that typically occur at every industry. Consequences (hazard) and likelihood (frequency) is similarly known as process to create accident. Therefore, safety is important to prevent risk and hazard to occur. In general, there are two strategies to reduce risk and hazard. It directed towards reducing the frequency and the consequences of potential accidents which can be classified into four categories which illustrate in Figure 1.

Figure 1: Hierarchy of Process Risk Management Strategies (Kletz, 2009)

Inherent safety which originally proposed by Kletz, (1978) uses the concept of eliminate or reduce hazard and it is difference from other categories. It removes or prevent hazard at the source while the others is accepting the hazard and attempting to mitigate the effects. There are many tools can be used to improve safety, but the most preferable and feasible method is inherent safety approach where the cost in time, capital and expenses is not required

Inherent safety is a concept of safety that focuses on eliminating or reducing hazard associated with a set of condition (Kletz, 2009). There are four main principles in inherent safety approach as illustrated in Table 2 below:

Table 2: Inherent Safety Principles (Kletz, 2009)

Principles	Definition
Minimize	Reduction in the quantity or quality
Substitute	Use safer methods
Moderate	Operate at safer condition or changing design or operation for less severe effects
Simplify	Avoidance of complexity

2.2.2.2 Integrated Inherent Safety Index (I2SI)

Khan and Amyotte (2005), has developed an integrated inherent safety index (I2SI) to consider the life cycle of the process with economic evaluation and hazard potential identification. The I2SI is composed of two sub-indices; hazard index and inherent safety potential index which consider hazard potential, inherent safety potential and add-on control requirements. However, I2SI is not suitable for human performance evaluation tool as the hazard index is intended to measure the damage potential of the process only. The index had been classified and specified to each process unit or parameter such as temperature, pressure, toxicity and etc.

2.2.2.3 Inherent Safety Index (ISI)

Inherent safety index is proposed by Heikkila et al (1996). It is simple and cost effective approach. It been designed to consider a range of factors affecting the inherent safety of a process. There are two categories in ISI which are chemical and process inherent safety. The chemical ISI describes the effect of the choice of raw materials and other chemicals on the inherent safety of the process with the consideration of heats of reaction, flammability, explosiveness, toxicity, corrosiveness, and incompatibility of chemicals. While process ISI describes the effect of the type of process equipment and conditions on inherent safety. Therefore, ISI tool is not recommended for human performance evaluation as it just focus on the process and chemical IS only.

2.2.2.4 Fuzzy Set Theory

Fuzzy theory is more efficient in the ranges selected for its index compared to indexing procedure. Fuzzy set theory is a modified method to improve sensitivity in the ranges selected for each of the index selected (Gentile, 2001). This method describes each factor by linguistic variable whose range of interests is divided into fuzzy sets.

Fuzzy based approach eliminates the problems existing in the indexing procedure approach and it is simple methodology for inherent safety evaluation (Gentile, 2001). Fuzzy theory for index computation is needed to quantify the sub-index and final index. Trapezoidal function (μ x) can be used to define the sub-index to calculate the crisp value. The membership function of the trapezoidal fuzzy number (TFN) can be referred at the Figure 2.

Fuzzy set theory involved fuzzy numbers which is known as fuzzy subset of real numbers. It is representing the extension of the confidence interval. Based on Laarhoven and Pedrycz (1983), a trapezoidal fuzzy number (TFN) have the following criteria.

1. There exists a $x_0 \in \mathbf{R}$ so that the degree of its membership $\mu m^{\sim} (x_0) = 1$;
2. Membership function $\mu m^{\sim} (x)$ is left and right continuous.

Let $m^{\sim} = (l, m1, m2, r)$ be a trapezium fuzzy number, where the membership function $\mu m^{\sim}$ of $m^{\sim}$ is

$$\mu_{\tilde{m}}(x) = \begin{cases} \frac{x-l}{m_1-l} & (l \leqslant x < m_1), \\ 1 & (m_1 \leqslant x \leqslant m_2), \\ \frac{r-x}{r-m_2} & (m_2 < x \leqslant r). \end{cases} \qquad (1)$$

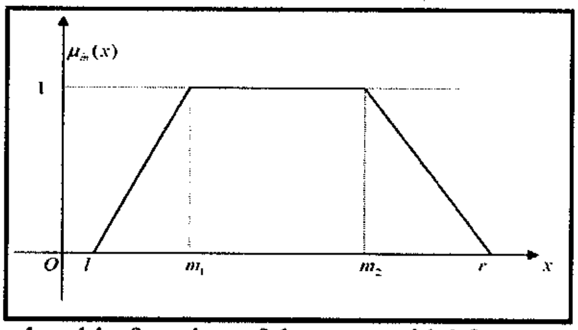

Figure 2: The membership function of the trapezoidal fuzzy number (Xia, 2006)

2.2.2.5 Linguistic Variables

Zadeh stated that, it is difficult for the conventional quantification to express the situations that too complex or difficult to define (Zadeh, 1975). Hence, a linguistic variable is needed to overcome the situation where the linguistic variables provide value in words or sentences in a natural language. Table 3 shows the intensity of important and definition of the linguistic variable and Figure 3 illustrates the example of membership function of linguistic variables for measuring the performance value of alternatives.

Table 3: Linguistic Variable Explanation (Xia, 2006)

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective.
3	Somewhat more important	Experience and judgment slightly favor one over the other.
5	Much more important	Experience and judgment strongly favor one over the other.
7	Very much more important	Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice.
9	Absolutely more important	The evidence favoring one over the other is of the highest possible validity.
2, 4, 6, 8	Intermediate values	When compromise is needed

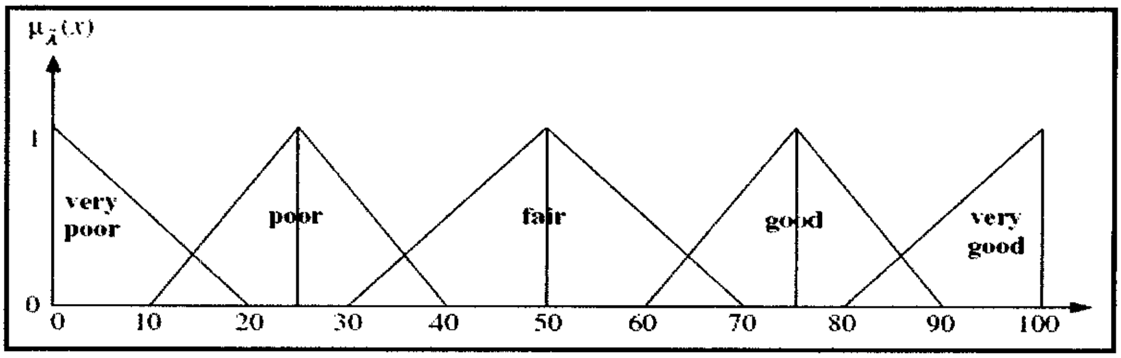

Figure 3: Example of membership function of linguistic variables for measuring the performance value of alternatives (Xia, 2006)

2.2.2.6 Fuzzy Analytical Hierarchy Process (FAHP)

There are several steps to be used for determining the weight evaluation criteria by FAHP which are:

1. Pairwise comparison matrices among all the elements and criteria in the factors. Considered the linguistic term to the pair wise comparisons by according to Table 3.

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \cdots & 1 \end{bmatrix}, \quad (2)$$

Where

$$\tilde{a}_{ij} = \begin{cases} \tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9}, & \text{criterion } i \text{ is relative importance to criterion } j, \\ 1, & i = j, \\ \tilde{1}^{-1}, \tilde{3}^{-1}, \tilde{5}^{-1}, \tilde{7}^{-1}, \tilde{9}^{-1}, & \text{criterion } i \text{ is relative less importance to criterion } j. \end{cases} \quad (3)$$

2. Use geometric mean technique to define the fuzzy geometric mean and lastly the fuzzy weight of each factor.

$$\tilde{a}ij = (\tilde{a}ij^1 \otimes \tilde{a}ij^2 \otimes \cdots \otimes \tilde{a}ij^n)^{1/n} \quad (4)$$

$$\hat{w}r1 = r_1 \otimes (r1 + r2 + r3 + \cdots \ldots + rn)^{-1} \quad (5)$$

Where ãij is the fuzzy comparison value of criterion I to j

r_i is the geometric mean of fuzzy comparison value of criterion i

ŵi is the fuzzy weight of the i^{th} criterion

CHAPTER 3
METHODOLOGY

3.0 HuP-FiST METHODOLOGY

HuP-FiST is a proactive and quantitative approach to identify human factor risk assessment. It been developed as a tool for identification, assessment and mitigation of hazard and risk due to human error. Figure 4 summarize the main steps of the HuP-FiST method. The result of this methodology provides the highest risk of human factor which then will be evaluated using HuP-FiST.

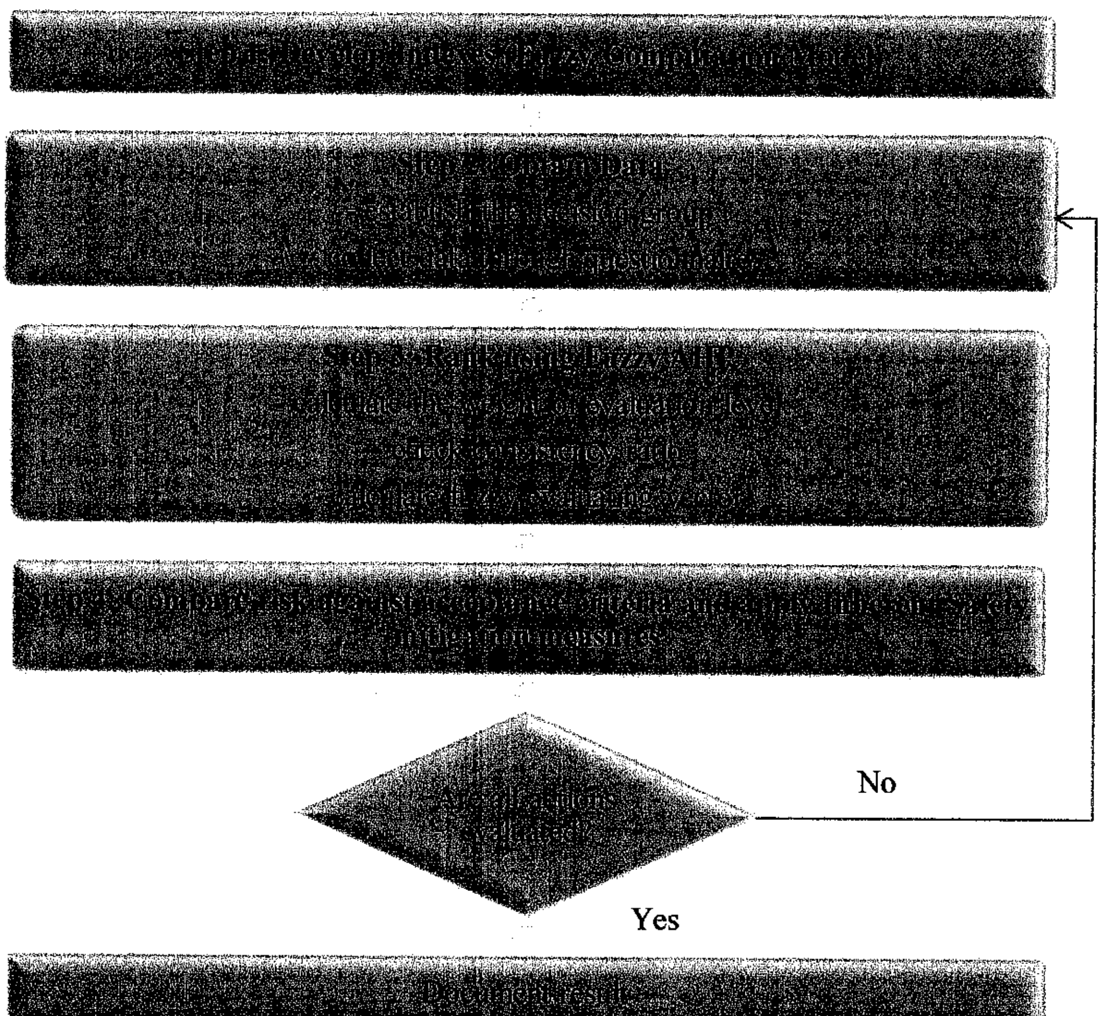

Figure 4: HuP-FiST Methodology

3.1 Step 1: Develop Index (Fuzzy Computation Model)

Proper index system is important for HuP-FiST methodology. Each HF has been assigned to their fuzzy index. Main HF lies at the first level while sub HF at the second level. The second level is the important criteria to satisfy the objectives of the project. The index (for example refers Table 4) will be used by the decision group to answer the hierarchy evaluation index constructed in Table 5.

Table 4: Fuzzy Index for Training (CCPS, 1994)

Human Factor	Description	Trapezoidal Fuzzy No.
3.2 Training	Operator is well trained and there is evidence of training manual, training programs as well as there is proof of feedback after training is carried out	[7,8,9,10]
	Operator is well trained and there is evidence of training manual, training programs but there is no proof of feedback after training is carried out	[5,6,7,8]
	Operators and personnel are trained and understand all cases including the critical parts	[3,4,5,6]
	Operators and personnel are trained but some cases where they do not understand some safety in the critical parts	[1,2,3,4]
	No training conducted to the operators and personnel on equipment and processes	[0,1,2,3]

*Refer Appendix A for other criteria

Table 5: HuP-FiST Hierarchy Evaluation Index (Kletz, 2009 & Zheng, 2012)

Go to next

Yes

		VP	P	M	G	VG
1.1 Work Nature	Would work nature influence occurrence of initiating event?					
1.2 Work Intensity	Would work intensity influence occurrence of initiating event?					
1.3 Work Schedules	Would work schedules influence occurrence of initiating event?					
1.4Manual Handling	Would manual handling influence occurrence of initiating event?					
2.1 Temperature	Would temperature influence occurrence of initiating event?					
2.2 Humidity	Would humidity influence occurrence of initiating event?					
2.3 Airflow Velocity	Would airflow velocity influence occurrence of initiating event?					
2.4 Heat Radiation	Would heat radiation intensity influence occurrence of initiating event?					
2.5 Lightning	Would lightning influence occurrence of initiating event?					
2.6 Noise	Would noise influence occurrence of initiating event?					
3.1 Experience	Would experience influence occurrence of initiating event?					
3.2 Training	Would training influence occurrence of initiating event?					
3.3Atmospheric Condition/PPE	Would atmospheric condition/PPE influence occurrence of initiating event?					
3.4Physical Condition	Would physical condition influence occurrence of initiating event?					
4.1 Procedures	Would procedures influence occurrence of initiating event?					
4.2 Communication	Would communication influence occurrence of initiating event?					
4.3 Label and Signs	Would label and signs influence occurrence of initiating event?					
5.1 Control Panels	Would design of control panels influence occurrence of initiating event?					
5.2 Displays	Would displays influence occurrence of initiating event?					
6.1 Facility Layout	Would facility layout influence occurrence of initiating event?					
6.2 Accessibility	Would accessibility influence occurrence of initiating event?					

3.2 Step 2: Obtain Data

3.2.1 Establish the Decision Group

In order to get different and wide view of the issues, fair and reliable evaluation group need to be considered. A decision group with different knowledge and expertise which is consists of management, professionals, workers, technicians, security and etc (Chen, 2009) is formed.

3.2.2 Collect Data through Questionnaire

The decision group will define the case study and compare the element of given HF in the hierarchy evaluation index constructed in Table 5. There are five level of grades which are very poor (VP), poor (P), medium (M), good (G) and very good (VG). Each member of the decision group required to give their judgment based on their expertise and knowledge of the HF listed. They need to "X" at the evaluation table by referring to the criteria at Appendix A and trapezoidal fuzzy number (TFN) evaluating value listed in Table 6. By evaluate the framework, the index of each HF can be obtained for next step of HuP-FiST methodology.

Table 6: Trapezoidal fuzzy number (TFN) evaluation list (Xia, 2006)

Linguistic variables	TFN
Very poor	[0, 1, 2, 3]
Poor	[1, 2, 3, 4]
Medium	[3, 4, 5, 6]
Good	[5, 6, 7, 8]
Very Good	[7, 8, 9, 10]

3.3 Step 3: Rank using Fuzzy AHP

3.3.1 Calculate the Weight of Evaluation Level

Commonly, 9-point scale (Saaty, 1990b) is used for the fuzzy analytical hierarchy process (FAHP) to represent the pair-wise comparison. In the HuP-FiST, TFN are used for the pair-wise comparison due to its efficiency and sensitivity. The scale of TFN to measure the comparison is given at Table 7.

Table 7: Scale of relative important used in pair-wise comparison (Mou, 2004)

Scale of relative important	TFN	Linguistic variable
1	[1 1 1 1]	Equally important
3	[2 5/2 7/2 4]	Weakly important
5	[4 9/2 11/2 6]	Essentially important
7	[6 13/2 15/2 8]	Very strongly important
9	[8 17/2 19/2 10]	Absolutely important
X = 2, 4, 6, 8 are intermediates scale X < 1 follow TFN scale 1	(x-1, x-1/2, x+1/2, x+1)	

Based on the TFN value determined by the decision group, the local weight of each HF is calculated. FAHP used as method to evaluate the weight of different level HF. Below are FAHP calculation process (Chou, 2012 & Wu, 2004)

1. According to the decision group relative important scale, the linguistic scale will be converted into TFN (refer Table 7). Then, the TFN will be applied to the pair-wise comparison matrix for calculation.

   Pair-wise comparison matrix:

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \cdots & 1 \end{bmatrix} \quad (6)$$

   Where $\tilde{a}_{ij}$ is the scale of Ti comparing with Tj.

2. Converting the element of pair-wise comparison matrix by using geometric mean method (Chen, 2009)

   $\tilde{a}ij = (\tilde{a}ij^1 \otimes \tilde{a}ij^2 \otimes \cdots \otimes \tilde{a}ij^n)^{1/n}$ (7)

   Example: 3x3 matrix

   $r\tilde{a}1 = (\tilde{a}11 \otimes \tilde{a}12 \otimes \tilde{a}13)^{1/3}$

   The remaining matrix elements can be obtained by same computational method where the value will be used to calculate the fuzzy weights.

3. Computational procedures to calculate fuzzy weights are as follows:

   $\hat{w}r1 = r_1 \otimes (r1 + r2 + r3 + \cdots \ldots + rn)^{-1}$ (8)

   Example: 3x3 matrix

   $\hat{w}r1 = r_1 \otimes (r1 + r2 + r3)^{-1}$

   The remaining element weights can be obtained using same computational method and fuzzy weight vector is produce as below:

   $\hat{W} = [\hat{w}1\ \hat{w}2\ \ldots\ \hat{w}n]$ (9)

4. Convert the TFN into matching crisp value using defuzzification method following below equation (Lin, 2006):

   $\tilde{A} = (a, b, c, d)$

   $N = \frac{(a+2b+2c+d)}{6}$ *where N is the defuzzified crisp value* (10)

3.3.2 Check Consistency Ratio (CR)

Consistency check of pair-wise comparison matrix can be calculated using consistency ratio (CR). Following are the steps to check the CR:

$CR = CI / RI$ (11)

Where $CI = (\lambda max - n)/(n - 1)$; λmax is the eigenvalue and n is the matrix size

RI is the random index where it can be obtained from the Table 8 below.

Table 8: The random consistency index (Konstantinos, 2005)

Size (n)	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

As a rule, the CR value must be less or equal to 0.1 or 10% to ensure the matrix is consistent and acceptable. If the CR value greater than 0.1, the pair-wise comparison matrix need to be revised.

3.3.3 Calculate Fuzzy Evaluating Vector

Fuzzy evaluating vector is calculated by using the ranking evaluation index in Table 5, TFN in Table 6 as well as the weight vector. The calculation is as follows:

1. Fuzzy evaluating matrix

   The matrix is given by the decision group obtained from the ranking evaluation index in Table 5.

   $\tilde{U}j = \frac{1}{k}\left((n.\tilde{u}j)^1 + (n.\tilde{u}j)^2 + \cdots (n.\tilde{u}j)^k\right)$ (12)

   Where k = number of decision maker

   $\tilde{U}$ = TFN for linguistic variable

   n = total decision maker of the linguistic variable for certain attribute

   Fuzzy evaluating matrix can be obtained as follows:

   $\tilde{U} = [\tilde{u}1\ \tilde{u}2 \ldots\ldots \tilde{u}n]$ (13)

2. Fuzzy evaluating vector

   In order to obtain fuzzy evaluating vector for final result of the HF evaluation, weight $\hat{w}j$ and fuzzy evaluating matrix, $\tilde{U}j$ will be used. The equation is as follows:

   $\check{Z} = ((\hat{w}1 \otimes \tilde{u}1) + (\hat{w}2 \otimes \tilde{u}2) + \ldots\ldots + (\hat{w}j \otimes \tilde{u}j)\ \phi\ (\hat{w}1 + \hat{w}2 + \ldots\ldots \hat{w}j))$ (14)

3.4 Step 4: Compare risk against acceptance criteria and apply Inherent Safety mitigation measures

Next step is to relate fuzzy evaluating vector, $\check{Z}$ with trapezoidal fuzzy number (TFN) evaluation list (refer Table 6). The advantage of this relation is, it flexibility and sensitivity to identify which HF has high risk and high potential of severity. Refer to Table 9 and 10 as a guideline to decide the applicability of Inherent Safety (IS) principles. Finally, mitigation measures are suggested for the specific HF to lower the risk based on IS principles (minimize, substitute, moderate and simplify).

Table 9: Guideline to decide the requirement of the control measurements (Khan, 2005)

Extent of Requirement	Description
0-2	Essential important
3	Very important
4	Important
5	Not greatly important but required
6	Required
7	Requirement is moderate
8	Good if available
9	Requirement does not affect process
10	Not required

*Green refer to case study rating

Table 10: Guideline to decide the applicability of IS principles (Khan, 2005)

Extent Indicator	Description
0-1	Completely applies IS or simplified the design to large extent and hazard is eliminated
2	Completely applied IS or simplified the design to large extent and most significant hazard is reduced
3	Completely applied IS or simplified to large extent and hazard is reduced
4	Completely applied IS or simplified the design to large extent and hazard is moderately reduced
5	Significantly applied IS or simplified the design and hazard is eliminated
6	Significantly applied IS or simplified the design and hazard is reduced
7	IS is applicable or simplified moderately the design and hazard may be reduced
8	IS is applicable or simplified moderately the design and hazard may be reduced moderately
9	IS may be applicable or no significant to simplified the design and hazard may be eliminated/reduced moderately
10	IS may be applicable or no significant to simplified the design and hazard may be reduced/no significant hazard reduction

*Green refer to case study rating

CHAPTER 4
RESULT AND DISCUSSION

4.1 RESULT

4.1.1 Case Study

The case study illustrates a coal mine in Shandong (Zheng, 2012) to represent the safety evaluation and early warning rating of the hot and humid environments. Coal mine Shandong is known as typical hot and humid environment (Zheng, 2012). Therefore it is selected to validate the use of the proposed FAHP for HuP-FiST methodology presented above. The main coal layers of the coal mine are 800–1000 m below the ground level and some of the coal layers are even more than 1000 m below the ground level. The environment parameters (dry bulb temperature, wet bulb temperature, WBGT, and airflow velocity) of a mining surface at a depth of more than 1000 m below surface level are measured. The length of the mining surface is about 400 m. There is only a draught fan installed for tunnel ventilation and no cooling system is used. The measurement results of the mining surface are given in Table 11.

Table 11: Measurement results of the mining surface (Zheng, 2012)

Environment Parameter	Return Air	Work Surface	Supply Air
Dry bulb temperature (°C)	33.1	31.6	31
Wet Bulb temperature (°C)	32.6	31.2	30.4
WBGT (°C)	32.5	31.3	30.4
Mean temperature of the wall(°C)	34.5	31.8	30.8
Airflow velocity (m/s)	7.0	2.5	2.2

*WBGT = wet bulb globe temperature

Steps to be used for the case study are as follows:

4.1.2 Step 2: Obtain Data

4.1.2.1 Establish the Decision Group

A decision group consists of ten security professionals, five management technicians and five workers (Chen, 2009).

4.1.2.2 Collect Data through Questionnaire

Based on the hierarchy evaluation index system, there are 3 main factors which are work (C1), environment (C2) and worker (C3) and eleven sub-factors which are work nature (C11), work intensity (C12), work duration (C13), temperature (C21), humidity (C22), airflow velocity (C23), heat radiation intensity (C24), seniority structure - experience (C31), safety training (C32), personal protective (C33) and seniority structure – physical condition (C34). Total evaluation grades of the data collection can be obtained from Table 12.

Table 12: Summarization of initial data of the evaluation

	VP	P	M	G	VG
C1	4	21	25	6	4
C2	3	6	33	28	10
C3	5	15	29	25	6
C11	1	7	8	3	1
C12	2	10	6	1	1
C13	1	4	11	2	2
C21	0	0	9	8	3
C22	1	3	8	6	2
C23	1	2	10	5	2
C24	1	1	6	9	3
C31	0	1	8	9	2
C32	2	3	6	7	2
C33	1	3	6	8	2
C34	2	8	9	1	0

4.1.3 Step 3: Rank using Fuzzy AHP

4.1.3.1 Calculate the Weight of Evaluation Level

Firstly, pair-wise comparison matrix will be developed (equation 6) by the decision group to identify the contribution of each factors. The TFN values from Table 7 used to represent the linguistic variable. Then, the pair-wise comparison matrix (refer Appendix D) is converted using geometric mean method (equation 7) and the result is summarized at Table 13.

Table 13: Summarization of pair-wise matrix factors

C1	1.0000	1.1447	1.3572	1.4422
C2	1.2599	1.3572	1.5183	1.5874
C3	0.4368	0.4853	0.6437	0.7937
C11	1.0000	1.1447	1.3572	1.4422
C12	1.2599	1.3572	1.5183	1.5874
C13	0.4368	0.4853	0.6437	0.7937
C21	1.8612	2.2047	2.8047	3.0801
C22	0.9036	1.1067	1.5541	1.8612
C23	0.6043	0.6866	0.9036	1.0746
C24	0.3195	0.3490	0.4342	0.5000
C31	2.2134	2.3256	2.5343	2.6321
C32	2.2134	2.3256	2.5343	2.6321
C33	0.3799	0.3946	0.4300	0.4518
C34	0.3799	0.3946	0.4300	0.4518

Based on Table 13 result, weight of each factor can be calculated using equation (8). Then, each weight is converted into defuzzified crisp value using equation (10). The fuzzy weight vector, $\hat{W}$ and defuzzified value are summarized at the Table 14.

Table 14: Summarization of fuzzy weight vector, $\hat{W}$ and defuzzified value

	Fuzzy Weight Vector, $\hat{W}$				Defuzzified weight
C1	0.2616	0.3253	0.4543	0.5348	0.3926
C2	0.3295	0.3857	0.5083	0.5886	0.4510
C3	0.1142	0.1379	0.2155	0.2943	0.1859
C11	0.2616	0.3253	0.4543	0.5348	0.3926
C12	0.3295	0.3857	0.5083	0.5886	0.4510
C13	0.1142	0.1379	0.2155	0.2943	0.1859
C21	0.2856	0.3870	0.6452	0.8350	0.5308
C22	0.1387	0.1943	0.3575	0.5046	0.2911
C23	0.0927	0.1205	0.2079	0.2913	0.1735
C24	0.0490	0.0613	0.0999	0.1356	0.0845
C31	0.3589	0.3923	0.4658	0.5075	0.4304
C32	0.3589	0.3923	0.4658	0.5075	0.4304
C33	0.0616	0.0666	0.0790	0.0871	0.0733
C34	0.0616	0.0666	0.0790	0.0871	0.0733

4.1.3.2 Check Consistency Ratio (CR)

CR of pair-wise comparison matrix is calculated using equation (11) and result is summarizing at the Table 15 below:

Table 15: Summarization of CR Checking

Matrix size, n	Eigenvalue, λmax	CI = $(\lambda max - n) / (n - 1)$	RI	CR = CI / RI
3	3.11359	0.05679	0.58	0.09792
3	3.11359	0.05679	0.58	0.09792
4	4.220936	0.07365	0.90	0.08183
4	4.049069	0.01636	0.90	0.01817

The CR value is considered acceptable for each pair-wise comparison matrix as the CR value is below that 0.1 or 10%.

4.1.3.3 Calculate Fuzzy Evaluating Vector

Fuzzy evaluating matrix, Ũ is calculated based on Table 12 initial data by using equation (12). Thus, fuzzy evaluating matrix, Ũ can be obtained and fuzzy evaluation vector, Ž can be calculated (equation 14). The result is rate according to Table 6 evaluation list and summarized in Table 16.

Table 16: Summarization of fuzzy evaluating matrix, Ũ, fuzzy evaluation vector, Ž and rating

	Fuzzy Evaluating Matrix, Ũ				Fuzzy Evaluation Vector, Ž	Rating
C1	2.5667	3.5667	4.5667	5.5667	4.367[illegible]	M
C2	3.9375	4.9375	5.9375	6.9375	5.68581	M
C3	4.4833	5.8167	7.1500	8.4833	7.02390	M
C11	2.6500	3.6500	4.6500	5.6500	4.45104	M
C12	2.0000	3.0000	4.0000	5.0000	3.74[illegible]	P
C13	3.0500	4.0500	5.0500	6.0500	4.95542	M
C21	4.4000	5.4000	6.4000	7.4000	6.34274	G
C22	3.5500	4.5500	5.5500	6.5500	5.57758	M
C23	3.5500	4.5500	5.5500	6.5500	5.52940	M
C24	4.2500	5.2500	6.2500	7.2500	6.18123	G
C31	4.2000	5.2000	6.2000	7.2000	5.85063	G
C32	3.5000	4.5000	5.5000	6.5000	5.15063	M
C33	3.7500	4.7500	5.7500	6.7500	5.40125	G
C34	2.0000	3.0000	4.0000	5.0000	3.65125	P

*Green refer to the lowest rating

4.1.4 Step 4: Compare risk against acceptance criteria and apply Inherent Safety mitigation measures.

Next is to compare risk against acceptance criteria. Based on the rating in Table 16, most of the factors are between medium and good except for C12 (work intensity) and C34 (seniority structure – physical condition) which is poor. Among the three main HF, C1 (work) is the lowest value due to the low value of C11 (work nature) and C12 (work intensity) sub-factors. This result shows that, work as miners can easily get fatigue due to work nature, environment and intensity as well as their physical condition. As for the case study, the work nature and work intensity is not suitable for miner physical characteristics. Therefore, both work nature and work intensity factors need to be improved to enhance their physical condition.

Mitigation measures can be taken to reduce/eliminate work nature (C11), work intensity (C12) and physical condition (C34) risk based on Inherent Safety (IS) guideline in Table 9 and 10. By referring to Table 16, work nature (C11) rating is $4.45 \approx 4$, work intensity (C12) rating is $3.74 \approx 4$ while physical condition (C34) rating is $3.65 \approx 4$. As in Table 9 and 10, the extent of requirement is rely in important to control the hazard where mitigation measures that relevant are completely applied IS or simplified the design to large extent and hazard is moderately reduced. Mitigation measures proposed for this case study are as Table 17.

Table 17: Proposed Inherent Safety (IS) mitigation measures

Principles	Mitigation Measures	Applicability
Minimize	Reduce the miners work intensity and rearrange the work schedule. This can be done by limiting number of work hours up to 10 hour/day during 40 hour work /week for 1mg/m^3 time-weighted average (TWA) concentration exposure. As a result, it can reduce large fatigue dose effect from too intensive work and not enough chance to rest.	C11, C12, C13, C34
Substitute	Use safer methods to avoid high work intensity at prolong work hours. For example substitute manual handling and complex equipment in the mining work nature with less hazardous work intensity. Applied or substitute it by using auto-tools and auto-equipment to reduce stress and fatigue of the miners.	C11, C12, C13, C34
Moderate	Use moderate design of working environment and provide suitable procedures for miners to refer. For example, use less hazardous facility that can reduce hazard and risk in the mining area. Equipped all mining workers in mining area with two ways radios and gas detector.	C12, C21, C22, C23, C24, C34
Simplify	Avoid complexity of the work environment or work nature. Usually, mining involved complex and hectic environment especially for the coal mine dust. Therefore, simpler mining process and facility are needed to avoid hazard in the mining area.	C11, C22

4.2 DISCUSSION

Further discussion regarding HuP-FiST approach using FAHP method is done to confirm the sensitivity and reliability of the method. The results are compared with the proposed method by Zheng (2012) and Traditional Method (2009). The comparison of the methods illustrated at Table 18.

Table 18: Comparison of three methods

	HuP-FiST			Zheng's Method		Traditional Method	
	Fuzzy Matrix	F.Vector	Rating	Fuzzy Matrix	Rating	Fuzzy Matrix	Rating
C1	(2.57, 3.57, 4.57, 5.57)	4.37	M	(2.38, 3.37, 4.37, 5.39)	P, M	(0.077, 0.407, 0.370, 0.088, 0.058)	P
C2	(3.94, 4.94, 5.94, 6.94)	5.69	M	(3.93, 4.94, 5.94, 6.94)	M, G	(0.025, 0.109, 0.383, 0.354, 0.129)	M
C3	(4.48, 5.82, 7.15, 8.48)	7.02	M	3.62, 4.62, 5.62, 6.62)	M,G	(0.082, 0.122, 0.328, 0.382, 0.086)	G
C11	(2.65, 3.65, 4.65, 5.65)	4.45	M	(2.65, 3.65, 4.65, 5.65)	P,M	(0.05, 0.35, 0.40, 0.15, 0.05)	M
C12	(2.00, 3.00, 4.00, 5.00)	3.75	P	(2.00, 3.00, 4.00, 5.00)	P,M	(0.1, 0.5, 0.3, 0.05, 0.05)	P
C13	(3.05, 4.05, 5.05, 6.05)	4.96	M	(3.05, 4.05, 5.05, 6.05)	M,G	(0.05, 0.2, 0.55, 0.1, 0.1)	M
C21	(4.40, 5.40, 6.40, 7.40)	6.34	G	(4.20, 5.20, 6.20, 7.20)	M,G	(0.00, 0.10, 0.35, 0.40, 0.15)	G
C22	(3.55, 4.55, 5.55, 6.55)	5.58	M	(3.55, 4.55, 5.55, 6.55)	M,G	(0.05, 0.15, 0.4, 0.3, 0.1)	M
C23	(3.55, 4.55, 5.55, 6.55)	5.53	M	(3.55, 4.55, 5.55, 6.55)	M,G	(0.05, 0.1, 0.5, 0.25, 0.1)	M
C24	(4.25, 5.25, 6.25, 7.25)	6.18	G	(4.25, 5.25, 6.25, 7.25)	M,G	(0.05, 0.05, 0.3, 0.45, 0.15)	G
C31	(4.20, 5.20, 6.20, 7.20)	5.85	G	(3.85, 4.85, 5.85, 6.85)	M,G	(0.05, 0.05, 0.40, 0.45, 0.05)	G
C32	(3.50, 4.50, 5.50, 6.50)	5.15	M	(3.50, 4.50, 5.50, 6.50)	M, G	(0.1, 0.15, 0.30, 0.35, 0.10)	G
C33	(3.75, 4,75, 5.75, 6.75)	5.40	G	(3.75, 4.75, 5.75, 6.75)	M,G	(0.05, 0.15, 0.30, 0.40, 0.10)	G
C34	(2.00, 3.00, 4.00, 5.00)	3.65	P	-	-	-	-

*G=Good M=Medium P=Poor

Based on Table 18, it can be seen that HuP-FiST method is more sensitive and reliable compared to Zheng's Method (2012) and Traditional Method (2009). This is because, HuP-FiST used fuzzy vector as final result to identify the rating where Zheng's and Traditional method used only fuzzy matrix. This shows that, HuP-FiST more specific in term of factors rating which then will be used for Inherent Safety evaluation. In addition, HuP-FiST used widely HF compared to Zheng's and Traditional method. For example, C34 (physical condition) factor had been identify through the case study compared to the other two methods. For further discussion about the HuP-FiST method, Figure 5 and 6 illustrates the result of the computational method.

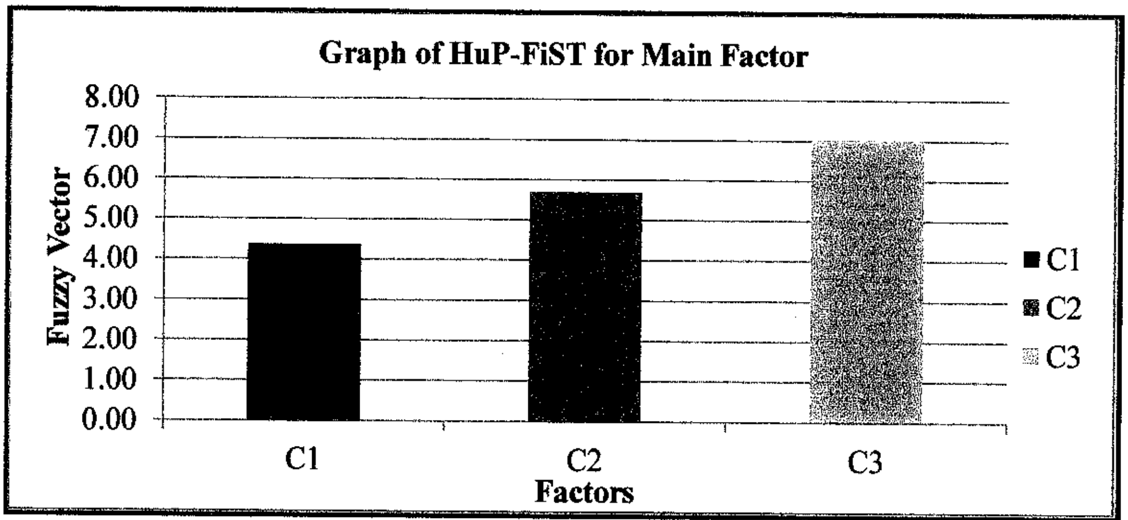

Figure 5: Graph of HuP-FiST for Main Factor

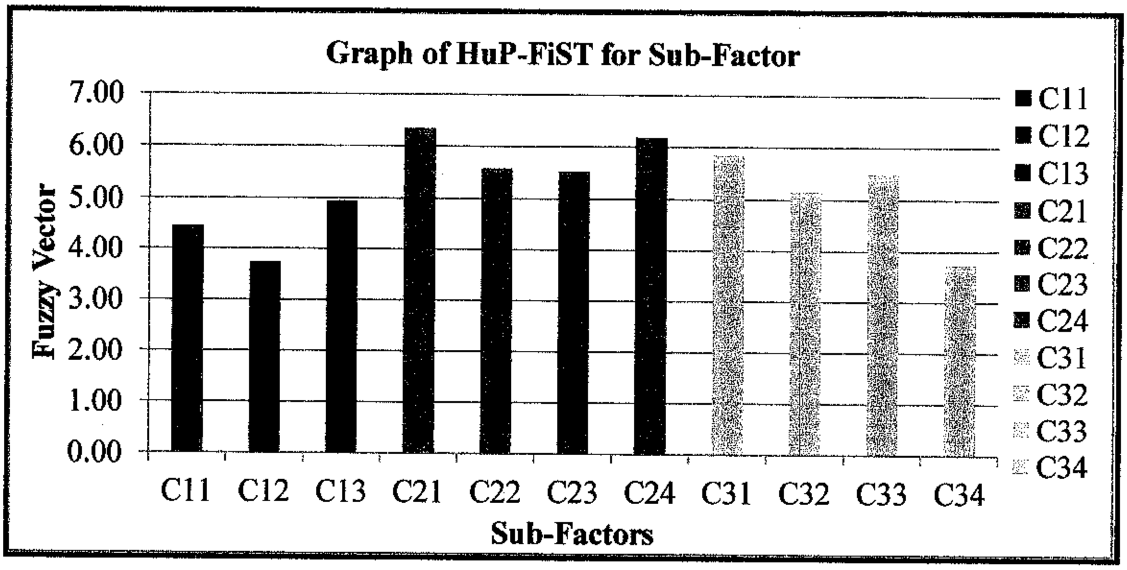

Figure 6: Graph of HuP-FiST for Sub-Factor

Based on Figure 5, it can be concluded that main factor C1 (work) is the lowest value compared to C2 (environment) and C3 (worker) factors. This is due to the lowest value of C11 and C12 sub-factors (refer Figure 6) which shows that work intensity and work nature in coal mining area is not good. Eventhough C34 among the poor sub-factor, it can be seen that sub-factor C31, C32 and C33 are rely in good and moderate rating (refer Table 18). As a result, C3 (worker) shows the highest main factor among the others. Followed by the C21, C22, C23 and C24 sub-factor which gives moderate value for C2 factor. Referring to the above discussion, mitigation measures need to be conducted to lower the risk due to these factors (refer Table 17).

The strength of the study may be due to some factors that had been modified from Zheng's (2012) and Traditional (2009) method which are:

1. HuP-FiST approach using wide human factors (HF) compared to Zheng's and Traditional main and sub-factors which just limited to several factors only. In fact, HF consists of various factors that need to be taken into consideration while conducted the evaluation.
2. HuP-FiST hierarchy evaluation index done by decision group is conducted based on specific and precise index. The index constructed at the index criteria and description table in Appendix A. This criteria and description is taken or constructed based on several references and literature review (CCPS, 1994, Kariuki, 2006 & Kletz, 2009).
3. TFN used as evaluation quantitative calculation instead of crisp number. This is because TFN shows precise and sensitive value compared to crisp number as fuzzy value is more widely in its range.
4. The TFN value for linguistic variable is simple and easy to understand compared to Zheng's and Traditional method. This is because, the TFN value is more straight forward where easier for the decision group to decide for the linguistic variable (pair-wise comparison).
5. This study used combination of FAHP and TFN which can make decision making and end result closer to the reality. Although these three methods are similar, HuP-FiST approach is more sensitive as it used fuzzy evaluating vector

to identify the end rating result compared to Zheng's and Traditional method. Zheng's and Traditional end their proposed method till the fuzzy evaluating matrix where the result is not precise to which linguistic variable HF is rely. As for HuP-FiST approach, the fuzzy evaluating vector gives specific result of the linguistic variable HF that need to be improved by the user.

6. The advantage of this method is the relation between fuzzy evaluating vector and TFN list. From the result, mitigation measure based on inherent safety principles will be taken to lower the risk.
7. Lastly, it is easy where it can be computed using Excel spreadsheet involving common and understandable mathematical operation.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

As the aim of the project is to develop a tool to reduce human error using Inherent Safety Tool (IST), the fuzzy analytical hierarchy process (FAHP) theory in index computation; a type of trapezoidal fuzzy number (TFN) is the best method to be used. There are a lot of methods had been introduced but most of them are develop for process and chemical purposes only. As in reality, human performance is actually the main factor that contributes to major accidents and need to be eliminated in order to ensure the plant operate as safe as possible from human error.

Inherent safety approach use basic application which is combination of FAHP and TFN to enhance safety and lower operating cost. It also an environmental friendly approach where it does not cause harm to people and environment. In addition, FAHP theory is the best method to be applied as it more sensitive and logic in its range compared to indexing method (traditionally method).

Thus, Inherent Safety Tool (IST) using fuzzy analytical hierarchy process (FAHP) or HuP-FiST is suitable to eliminate hazards or reduce the magnitude, severity or likelihood of occurrence by careful attention to human factor fundamental and layout issues.

Alternatively, there are also suggested future plans for continuation of the project. Future plans including to identify alternatives methods for the fuzzy evaluating matrix. Secondly, to consider and create HuP-FiST in the Excel visual basic application to ensure the tool is more users friendly. Thirdly, to improve the range selected for the comparison among the alternatives methods by using same benchmark (compare with specific range selected). Fourthly, to improve the proposed IS mitigation measure. It is recommended if the tool is more flexible which can be used by any methods of calculation which gives similar end result. Last but not least is to improve and identify how to differentiate the least and highest end result using IS or other methods.

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APPENDICES

Appendix A: Index Criteria and Description

1.0 Work/Job Design (JD)

Four important Job Design (JD) are work nature, work intensity, work schedule and manual handling. Normally, sleep loss, sleep disturbance and prolonged working hours up to 12 hours per day can cause fatigue and loss of concentration.

Table 1: Fuzzy Index for Work Nature

Human Factor	Description	Trapezoidal Fuzzy No.
1.1Work Nature	Excellent work condition with good temperature, good heat intensity, sufficient workload, adequate time for rest and good working environment.	[7,8,9,10]
	Good work condition with moderate temperature, moderate heat intensity, sufficient workload, have some time for rest and good working environment.	[5,6,7,8]
	Moderate work condition with moderate temperature, moderate heat intensity, moderate workload, have some time for rest and moderate working environment.	[3,4,5,6]
	Poor work condition with moderate temperature, moderate heat intensity, moderate workload, limited time for rest and complex working environment.	[1,2,3,4]
	Extreme work condition with high temperature, high heat intensity, high workload, limited time for rest and complex working environment.	[0,1,2,3]

Table 2: Fuzzy Index for Work Intensity

Human Factor	Description	Trapezoidal Fuzzy No.
1.2Work Intensity	Adequate work capacity, single tasking at one time and sufficient time for rest after working lead to excellent health condition	[7,8,9,10]
	Moderate work capacity, single tasking at one time and have some time for rest after working lead to good health condition	[5,6,7,8]
	Moderate work capacity, multitasking and have some time for rest after working lead to good health condition	[3,4,5,6]
	High work capacity, multitasking, have some time for rest after working but poor health condition	[1,2,3,4]
	High work capacity, multitasking, lack of time for rest after working and poor health condition	[0,1,2,3]

Source: European foundation for the improvement of living and working conditions.

Table 3: Fuzzy Index for Work Schedules

Human Factor	Description	Trapezoidal Fuzzy No.
1.3Work Schedule	Personnel and operators have work schedule/shift (less than 12 hours) and the work schedules is revised frequently for equitability	[7,8,9,10]
	Personnel and operators have work schedule/shift (less than 12 hours) but not revised frequently. Same person for same time.	[5,6,7,8]
	Personnel and operators have work schedule/shift but voluntarily request for 12 hours shift	[3,4,5,6]
	Personnel and operators have prolonged working hours (more than 12 hours)	[1,2,3,4]
	No work schedules for the operators and personnel	[0,1,2,3]

Table 4: Fuzzy Index for Manual Handling

Human Factor	Description	Trapezoidal Fuzzy No.
1.4 Manual Handling	Procedures for the manual handling exits in the company, clear, easy to be read and regularly revised from previous document	[7,8,9,10]
	Procedures for the manual handling exits in the company, clear but previous documentation is not clear	[5,6,7,8]
	Procedures for the manual handling exits in the company, clear but no documentation from previous document (rarely updated)	[3,4,5,6]
	Procedures for the manual handling exits in the company but not clear and difficult to understand	[1,2,3,4]
	No procedures for manual handling to be referred	[0,1,2,3]

2.0 Task Environment (TE)

As for the worker Task Environment (TE) consists of six main criteria which are thermal condition (temperature), thermal condition (humidity), airflow velocity, heat radiation intensity, lightning and noise. TE criteria are assumed to be important as it affect the psychological and physiological effects on performance.

Table 5: Fuzzy Index for Thermal Condition (Temperature/Humidity)

Human Factor	Description	Trapezoidal Fuzzy No.
2.1 Thermal Condition	Occupational exposure limit/guideline exits, clear and exposed to good thermal conditions without heat/cold stress as well as proper insulating cloth and personal protective equipment (below than 27°C for hot and below -31°C for cold)	[7,8,9,10]
	Occupational exposure limit/guideline exits, clear and exposed to good thermal conditions with proper insulating cloth and personal protective equipment (20 – 29°C for hot and -32 – -34°C for cold)	[5,6,7,8]
	Occupational exposure limit/guideline exits and exposed to moderate thermal conditions without heat/cold stress (30 – 39 °C for hot and -35 - -37 °C for cold)	[3,4,5,6]
	Occupational exposure limit/guideline exits and exposed to high thermal conditions (40 – 45°C for hot and -38 - -39°C for cold)	[1,2,3,4]
	No occupational exposure limit or guideline and exposed to extreme thermal conditions which cause heat/cold stress (exceeding 45°C or -40 - -42°C)	[0,1,2,3]

Source: Canadian Centre for Occupational Health and Safety

Table 6: Fuzzy Index for Airflow Velocity

Human Factor	Description	Trapezoidal Fuzzy No.
2.2 Airflow Velocity	Excellent thermal conditions without heat/cold stress and normal wind/airflow velocity	[7,8,9,10]
	Good thermal conditions of heat/cold stress and wind/airflow velocity at 8 km/hr (5 mph)	[5,6,7,8]
	Moderate thermal conditions of heat/cold stress and wind/airflow velocity at 16 km/hr (10 mph)	[3,4,5,6]
	Poor thermal conditions of heat/cold stress and wind/airflow velocity at 24 km/hr (15 mph)	[1,2,3,4]
	Poor thermal conditions of heat/cold stress and wind/airflow velocity at 32 km/hr (20 mph)	[0,1,2,3]

Source: Canadian Centre for Occupational Health and Safety

Table 7: Heat Radiation Intensity

Human Factor	Description	Trapezoidal Fuzzy No.
2.3 Heat Radiation Intensity	Good heat radiation intensity with heat at 28.0°C for acclimatized and 25.0°C for unacclimatized action limit	[7,8,9,10]
	Good heat radiation intensity with heat at 29.0°C for acclimatized and 26.0°C for unacclimatized action limit	[5,6,7,8]
	Moderate heat radiation intensity with heat at 30.0°C for acclimatized and 27.0°C for unacclimatized action limit	[3,4,5,6]
	Poor heat radiation intensity with heat at 30.5 °C for acclimatized and 28.0°C for unacclimatized action limit	[1,2,3,4]
	Poor heat radiation intensity with heat at 31.5°C for acclimatized and 29.0°C for unacclimatized action limit	[0,1,2,3]

*Assumes 8 hour/days in a 5 day/week with conventional breaks

*All values are for moderate acclimatized and unacclimatized action limit.

Table 8: Fuzzy Index for Lightning

Human Factor	Description	Trapezoidal Fuzzy No.
2.4 Lightning	Excellent lightning almost to every parts, clear and uninterrupted glare	[7,8,9,10]
	Good lightning and uninterrupted glare but not clear	[5,6,7,8]
	Good lightning to critical and important parts but direct and reflected glare	[3,4,5,6]
	Poor lightning to read valves and instrument scale especially at the critical and important parts	[1,2,3,4]
	No lightning at critical and important valves and equipment	[0,1,2,3]

Table 9: Fuzzy Index for Noise

Human Factor	Description	Trapezoidal Fuzzy No.
2.5 Noise	No distraction and normal intensity and frequency of noise exposure at 85 dB or less with maximum exposure 8 hours per day	[7,8,9,10]
	No distraction and intensity and frequency of noise exposure is at 91 dB with maximum exposure 2 hours per day	[5,6,7,8]
	Little distraction and communication with moderate intensity and frequency of noise exposure at 100 dB with maximum exposure 15 minutes per day	[3,4,5,6]
	Distraction and communication difficulties with high intensity and frequency of noise exposure at 124 dB with maximum exposure 3 seconds per day	[1,2,3,4]
	High intensity and frequency of noise exposure is at 140 dB or more	[0,1,2,3]

Source: United State Department of Labor

*Refer Appendix B for guideline

3.0 Worker/Operator Characteristics (OP)

Operator Characteristics (OP) concerns the personnel characteristics which are experience, training, atmospheric condition/PPE and physical condition criteria. Good training, degree of skills and experience are the elements that need to take heavily in order to maintain operator characteristic.

Table 10: Fuzzy Index for Experience

Human Factor	Description	Trapezoidal Fuzzy No.
3.1 Experience	Good degree of skill to applied knowledge to real life problems (time pressure, high workload), have previous stressful experience (more than 20 years), have clear instructional methods/procedures and good training on new or critical equipment, processes or simulator	[7,8,9,10]
	Good degree of skill to applied knowledge to real life problems (time pressure, high workload) and have previous stressful experience (experience between 15-20 years) but no clear instructional methods/procedures	[5,6,7,8]
	Moderate degree of skill to applied knowledge to real life problems (time pressure, high workload) and have previous stressful experience (experience between 7-15 years) but no training regarding new equipment processes or simulator	[3,4,5,6]
	Little degree of skill to applied knowledge to real life problems (time pressure, high workload) and no previous stressful experience (experience between 3-6 years)	[1,2,3,4]
	No skills, knowledge and experience on related expertise or no training regarding equipment, processes or simulator	[0,1,2,3]

Table 11: Fuzzy Index for Training

Human Factor	Description	Trapezoidal Fuzzy No.
3.2 Training	Operator is well trained and there is evidence of training manual, training programs as well as there is proof of feedback after training is carried out	[7,8,9,10]
	Operator is well trained and there is evidence of training manual, training programs but there is no proof of feedback after training is carried out	[5,6,7,8]
	Operators and personnel are trained and understand all cases including the critical parts	[3,4,5,6]
	Operators and personnel are trained but some cases where they do not understand some safety in the critical parts	[1,2,3,4]
	No training conducted to the operators and personnel on equipment and processes	[0,1,2,3]

Table 12: Fuzzy Index for Atmospheric Condition

Human Factor	Description	Trapezoidal Fuzzy No.
3.3Atmospheric Condition	Good atmospheric condition (dust, fumes, gases) and appropriate personal protective equipment (PPE) and apparatus been used to finished work properly	[7,8,9,10]
	Good atmospheric condition (dust, fumes, gases) and inadequate personal protective equipment (PPE) and apparatus been used to finished work properly	[5,6,7,8]
	Moderate atmospheric condition (dust, fumes, gases) and inappropriate personal protective equipment (PPE)	[3,4,5,6]
	Poor atmospheric condition (dust, fumes, gases) and inappropriate personal protective equipment (PPE) in order to finished work quickly	[1,2,3,4]
	Poor atmospheric condition (dust, fumes, gases) and no personal protective equipment (PPE)	[0,1,2,3]

Table 13: Fuzzy Index for Physical Characteristic

Human Factor	Description	Trapezoidal Fuzzy No.
3.4 Physical Condition	Good health and fitness factor, capable to work at high workload, efficient, high level of experience and good age factor	[7,8,9,10]
	Good health and fitness factor, inefficient, intermediate level of experience and age factor	[5,6,7,8]
	Intermediate health factor, experience workers and age factor (older or young)	[3,4,5,6]
	Poor health factor, inexperienced workers and age factor (older or young)	[1,2,3,4]
	Decrease in visual ability (fine scale), decrease in capacity of process information, loss of working memory (long period), age and health factor	[0,1,2,3]

4.0 Information (IN)

For first dimension, Information (IN) consists of three evaluation criteria which are procedures, communication and label and signs.

Table 14: Fuzzy Index for Procedures

Human Factor	Description	Trapezoidal Fuzzy No.
4.1 Procedures	Procedures exits in the company easy to read and highlight some modification that had been done on the system as well as frequently updated	[7,8,9,10]
	Procedures exits in the company easy to read and highlight some modification that had been done on the system but rarely updated	[5,6,7,8]
	Procedures exit in the company easy to read but do not highlight important modification that had been done on the system	[3,4,5,6]
	Procedures exits in the company but difficult to understand and too long	[1,2,3,4]
	No procedures exits in the company	[0,1,2,3]

Table 15: Fuzzy Index for Communication

Human Factor	Description	Trapezoidal Fuzzy No.
4.2 Communication	Personnel and operators communicates to each other's and understand the information given, clearly know the procedures and good skill and knowledge	[7,8,9,10]
	Personnel and operators communicates to each other's and understand the information given but no skills and knowledge	[5,6,7,8]
	Personnel and operators communicates to each other's and understand the information given but not clearly know the procedures	[3,4,5,6]
	Personnel and operators communicates to each other's but misunderstand the information given	[1,2,3,4]
	No communication among the personnel and operators (absence of communication)	[0,1,2,3]

Table 16: Fuzzy Index for Label and Signs

Human Factor	Description	Trapezoidal Fuzzy No.
4.3Label and Signs	Equipment and system is labeled, clear and easy to be read as well as easy to be reached and regularly checked and changed	[7,8,9,10]
	Equipment and system is labeled, clear and easy to be read but not regularly checked and changed	[5,6,7,8]
	Equipment and system is labeled, clear and easy to be read but the label is too difficult to be reached	[3,4,5,6]
	Equipment and system is labeled but not clear and cannot be read	[1,2,3,4]
	No label and signs on the equipment or systems	[0,1,2,3]

5.0 Human System Interface (HSI)

Human System Interface (HIS) consists of two main evaluation criteria which are design of control panels and display. Control panel relates to the instrumentation normally in the central control room where workers communicate with the process information by change the control panel state of the process or where desired.

Table 17: Fuzzy Index for Design of Control Panels

Human Factor	Description	Trapezoidal Fuzzy No.
5.1 Design of Control Panels	Sufficient information exits, clear, relevant to the process, regularly updated from time to time and appropriate amount of control panel and not too complex or too far from each other	[7,8,9,10]
	Appropriate amount of control panels, sufficient information exits, clear, relevant to the process but rarely updated	[5,6,7,8]
	Information exits but too much redundant information which not clear and overload the workers as difficult to reach one another control panels	[3,4,5,6]
	Information exits but too little, not relevant to the process, not clear and least amount of control panels	[1,2,3,4]
	No information regarding control panel, design too complex and too difficult to reach one another	[0,1,2,3]

Table 18: Fuzzy Index for Displays

Human Factor	Description	Trapezoidal Fuzzy No.
5.2 Displays	Coding for controls and displays clear and easy to be read and differentiate. Adequate separation line for the tolerance limit in order to understand the situation	[7,8,9,10]
	Coding for controls and displays clear and easy to be read and differentiate as well as sufficient separation line for the tolerance limit but too difficult to understand the situation	[5,6,7,8]
	Coding for controls and displays available, clear and easy to be read but difficult to differentiate (similar coding) and sufficient separation line for tolerance limit	[3,4,5,6]
	Coding available but not clear and lack of separation lines for the tolerance limit at various critical parameters.	[1,2,3,4]
	No coding for every controls and displays (label, color, shape, location and size)	[0,1,2,3]

6.0 Workplace Design (WD)

Good plant considered good Workplace Design (WD) which includes good access and controls and instrumentations is label properly and clearly. Two major criteria in the WD are facility layout and accessibility.

Table 19: Fuzzy Index for Facility Layout

Human Factor	Description	Trapezoidal Fuzzy No.
6.1 Facility Layout	Full description of facility layout/documents/procedures exits, clear and revised from time to time and consistent layout label at the workplace design	[7,8,9,10]
	Facility layout exits at the workplace design and consistent layout label	[5,6,7,8]
	Facility layout exits and consistent layout label but not clear and not revised from time to time	[3,4,5,6]
	Facility layout exits but too complex and wrong layout or label at the workplace design	[1,2,3,4]
	No facility layout, documents or procedures of the workplace design	[0,1,2,3]

Table 20: Fuzzy Index for Accessibility

Human Factor	Description	Trapezoidal Fuzzy No.
6.2 Accessibility	Good accessibility and procedures available at the workplace design is understandable, revised from time to time and clear labeling of the valves, fittings and small equipment	[7,8,9,10]
	Convenience accessibility and procedures available at the workplace design is understandable but label of the valves, fittings and small equipment not clear	[5,6,7,8]
	Accessibility but procedures available at the workplace design too complex (understandable) and not revised from time to time	[3,4,5,6]
	Accessibility but procedures available at the workplace design not correct	[1,2,3,4]
	Accessibility is too small or too complex at the workplace design	[0,1,2,3]

Appendix B: Guideline for Maximum Recommended Noise Dose Exposure Levels

Table 1: Maximum recommended noise dose exposure levels

Noise Level (dBA)	Maximum Exposure Time per 24 Hours	
85	8 hours	Very Good
88	4 hours	
91	2 hours	Good
94	1 hour	
97	30 minutes	
100	15 minutes	
103	7.5 minutes	Medium
106	3.7 minutes	
109	1.9 minutes	
112	56 seconds	
115	28 seconds	
118	14 seconds	
121	7 seconds	Poor
124	3 seconds	
127	1 second	
130–140	less than 1 second	
140	**NO EXPOSURE**	Very Poor

Appendix C: Gantt chart

Table 1: Gantt Chart and key milestone

No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Work Continues	■	■	■	■	■	■	MID SEMESTER BREAK							
2	Submission of Progress Report								●						
3	Project Work Continues								■	■	■	■	■		
4	Pre-EDX											●			
5	Submission of Draft Report											●			
6	Submission of Dissertation (soft bound)												●		
7	Submission of technical paper													●	
8	Oral Presentation														●
9	Submission of Project Dissertation (hard bound)														●

● Suggested Milestones ■ Process

Appendix D: Pair-Wise Comparison Matrix

Table 1: Pair-wise comparison matrix of the main factors

	C1				C2				C3			
C1	1	1	1	1	1	1	1	1	1	1 1/2	2 1/2	3
C2	1	1	1	1	1	1	1	1	2	2 1/2	3 1/2	4
C3	1/3	2/5	2/3	1	1/4	2/7	2/5	1/2	1	1	1	1

Table 2: Pair-wise comparison matrix of the sub-factors within work (C1)

	C11				C12				C13			
C11	1	1	1	1	1	1	1	1	1	1 1/2	2 1/2	3
C12	1	1	1	1	1	1	1	1	2	2 1/2	3 1/2	4
C13	1/3	2/5	2/3	1	1/4	2/7	2/5	1/2	1	1	1	1

Table 3: Pair-wise comparison matrix of the sub-factors within environment (C2)

	C21				C22				C23				C24			
C21	1	1	1	1	1	1 1/2	2 1/2	3	3	3 1/2	4 1/2	5	4	4 1/2	5 1/2	6
C22	1/3	2/5	2/3	1	1	1	1	1	1	1 1/2	2 1/2	3	2	2 1/2	3 1/2	4
C23	1/5	2/9	2/7	1/3	1/3	2/5	2/3	1	1	1	1	1	2	2 1/2	3 1/2	4
C24	1/6	1/5	2/9	1/4	1/4	2/7	2/5	1/2	1/4	2/7	2/5	1/2	1	1	1	1

Table 4: Pair-wise comparison matrix of the sub-factors within worker (C3)

	C31				C32				C33				C34			
C31	1	1	1	1	1	1	1	1	4	4 1/2	5 1/2	6	6	6 1/2	7 1/2	8
C32	1	1	1	1	1	1	1	1	6	6 1/2	7 1/2	8	4	4 1/2	5 1/2	6
C33	1/6	1/5	2/9	1/4	1/8	1/7	1/6	1/6	1	1	1	1	1	1	1	1
C34	1/8	1/7	1/6	1/6	1/6	1/5	2/9	1/4	1	1	1	1	1	1	1	1