Estimating the human error probability using the fuzzy logic approach of CREAM (The case of a control room in a petrochemical industry)

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Abstract: Cognitive Reliability and Error Analysis Method (CREAM) is one of the Second Generation methods of human reliability analysis (HRA) that focus on the contextual conditions in which the task is performed. The second generation method of HRA was developed to address the limitation of the First Generation methods, which their center of attention was inherent human error probabilities with less attention to the conditions of the workplace. The CREAM benefits from two methods of quantification namely, Basic, and Extended methods. The Basic method is a rapid and simple way to estimate the probability of human error based on the level of control that operators have on their performance. However, the result obtained by this method is an interval value rather than a specific value that can be used in quantitative risk assessment (QRA) methods. To overcome this issue, a fuzzy logic approach was developed on the basis of CREAM methodology. In this research, the fuzzy modeling of CREAM is applied to estimate a crisp value for probability of human action erroneous in a quick and quantitative manner. The method is used to calculate the human error probability (HRA) in a control room of a petrochemical industry.

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1. Introduction

Despite the improvement in safety knowledge and process design, still accidents, whether harmless or catastrophic disasters, occur in various industries. The reason is known as human error that has caused accidents such as Bhopal, Three Mile Island, Chernobyl, and Piper Alpha disasters, which have lead to catastrophic consequences [1, 2]. There is a separate need for assessing the risk from human errors, to decrease the probability of human action failure which leads to the accident. This need can be achieved by Human Reliability Analysis (HRA). The purpose of HRA is to predict the probable failures in a task caused by a human error [3]. Numerous methods have been developed as teamwork of engineers and psychologists, to assist the analysis of human errors and human reliability. Most of them include expert judgment techniques, simulation techniques, classical mathematical evaluation methods, and well defined procedures such as fault trees or event trees [4, 5].

During 1970s and 1980s, the early methods of HRA were developed which are known as First Generation Methods of HRA[6]. In First Generation HRA methods such as THERP (Technique for Human Error Rate Prediction) [5], ASEP (Accident Sequence Evaluation Program) [7] and HCR (Human Cognition Reliability) [8] SLIM (Success Likelihood Index Methodology) [9] and HEART(Human Error Assessment and Reduction Technique) [10], human is seen as an electrical or mechanical component which has an inherent deficiency. Thus, characteristics of the task that human has to perform, play the main role in prediction of human error probability, while the environment effects which are called performance shaping factors(PSF), are in a lower degree of significance[11,12]. However, there are some limitations for the first generation methods. For instance, they focused on human inherent failure without precise analysis of decision making process or incorporating contextual factors which influence the action of human. [13, 14].

As times go on, these problems were addressed by means of new methods of HRA that are called Second Generation Methods of HRA such as cognitive reliability and error analysis method (CREAM) [15], a technique for human error analysis (ATHEANA) [16], SPAR-H [17] and MDTA [18]. In contrast to the old view of human error that says human error is the cause of many accidents, the novel view of human error, based on which the second generation methods were developed, is based on this fact that the human error is the symptom of contradictions, pressures and resource limitations deeper inside the system [19]. The significant characteristic of second generation methods is that they focus on contextual factors and their contribution in quantification of human error analysis. In fact the context or environment contributes as the major factor and the characteristic of the task plays a minor role in the fore mentioned analysis methods [11, 12].

Cognitive Reliability and Error analysis method (CREAM) is a well structured method which contribute the influence of context or environment conditions to human error probability. CREAM benefits from two methods of quantification namely, Basic and Extended methods. The former is usually used in screening goals to find out the level of control that operators have on their work, and also to estimate an approximate interval for prediction of human error probability (HEP). Due to some uncertainties, and lack of an exact value for HEP in the result of Basic method, a fuzzy logic approach is applied in this work to calculate a crisp value for estimating the probability of human failure. Fuzzy logic approach of Basic CREAM is implemented in a case study of a control room at a petrochemical industry in Iran.

2. Common performance condition (CPCs) and control modes

CREAM is based on the contextual control mode COCOM in which the control that an operator has on their work, determines the probability of human error. Nine CPCs in CREAM methodology are defined, evaluated and given ranked to illustrate the characteristics of the context in which the task is performed. They are also used in fuzzy logic method to develop the fuzzy sets. Each CPC has a certain number of levels and each level represents that how it affect the performance of the operator. For instance, the CPC "working conditions" has three levels, namely, advantageous, compatible, and incompatible, with respectively, improved (positive), not significant and reduced (negative) effect on performance reliability. These CPCs with their levels and effects are described in table 1. [12]

In Basic quantification method of CREAM, human error probability is estimated by defining the level of control that operators have on their performance. Four levels of control mode are considered in CREAM such as [15p156]:

(1) Scrambled control mode, represents the context in which the operator decides what to do with little or no thinking.

(2) Opportunistic control mode, describes the situatoin in which the person performs the tasks using their experiences or habit that is most frequently used rather than well planning or anticipation.

(3) Tactical control, signifys a situation in which the person acts based on a procedure and rule, though, there are sometimes a limitation in planning.

(4) Strategic control mode means that operator has an efficient control on their work thanks to the well structured conditions of workplace.

For each type of control mode the interval value of human error probability is defined as can be seen in table 2. The level of control is chosen based on the level of CPCs, simply by counting the number of negative (reduce) and positive (improved) CPCs and using the figure 1.

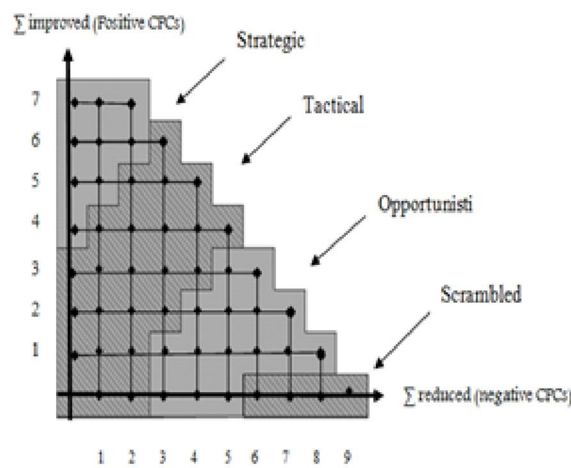

Figure 1. Relations between control modes CPC score and control modes

Table 1. CPCs and their levels, effects, and fuzzy sets

CPC	Number of fuzzy set	CPC level	Effect
Adequacy of organization	4 [0-100]	Deficient	Reduced
		Inefficient	Reduced
		Efficient	Not significant
		Very efficient	Improved
Working conditions	3 [0-100]	Incompatible	Reduced
		Compatible	Not significant
		Advantageous	Improved
Adequacy of man machine interface (MMI) and operational support	4 [0-100]	Inappropriate	Reduced
		Tolerable	Not significant
		Adequate	Not significant
		Supportive	Improved
Availability of procedures/plans	3 [0-100]	Inappropriate	Reduced
		Acceptable	Not significant

		Appropriate	Improved
Number of simultaneous goals	3 [0-100]	More than actual capacity	Reduced
		Matching current capacity	Not significant
		Fewer than actual capacity	Not significant
Available time	3 [0-100]	Continuously inadequate	Reduced
		Temporarily inadequate	Not significant
		Adequate	Improved
Time of the day (circadian rhythm	3 [0-24]	Night(unadjusted)	Reduced
		Day (adjusted)	Not significant
		Night (unadjusted)	Reduced
Adequacy of training and experience	3 [0-100]	Inadequate	Reduced
		Adequate with limited experience	Not significant
		Adequate with high experience	Improved
Crew collaboration quality	4 [0-100]	Deficient	Reduced
		Inefficient	Not significant
		Efficient	Not significant
		Very efficient	Improved

Table 2. Control modes and human error probability

Control mode	***Probability of action failure***
Strategic	*0.00005‹P‹0.01*
Tactical	*0.001‹P‹0.1*
Opportunistic	*0.01‹P‹0.5*
Scrambled	*0.1‹P‹1.0*

3. Fuzzy logic approach of CREAM

As can be perceived from the previous explanation about the Basic CREAM, the result obtained from this method is only an interval value for human error probability rather than a clear specific value. In addition, human reliability analysis is inherently subjective [21]. Therefore, there is a need to a method by which subjective data can be incorporated and be able to predict a precise value for probability of human error, based on the contextual characteristics. To these aims, the fuzzy logic approach, which is based on the common performance conditions in CEAM, has been developed.[12] The modeling is implemented in software MATLAB. Deifferent steps of this approach are briefly described as bellow:

1) The first step in fuzzy logic approach is to define the input and output variables and their fuzzy sets. The lingustic descriptoin of the CPCs levels are accounted as the fuzzy sets. For instnace, for CPC 'adequacy of organization' there are 4 fuzzy sets which are defined in a rating range of between 0 and 100. Nine CPCs are considered as input variables and the type of control mode which defines the Human Error Probability (HEP) is considered as the unique out-put variable. Number of the fuzzy sets and the rating range for all nine CPCs(input variables), and control modes or HEP (output variable) are illustrated in table 3. In addition, Figure 2. Shows these triangulare fuzzy sets which are defined in software Matlab.

2) The next step, is making the fuzzy rules by combining 9 CPCs by a logical AND operator. Since three CPCs have 4 possible level and six CPCs have 3 possible level, the total number of rules is N= 4^(3)× 3^6 = 46565. Consequence result is defined based on CREAM methodology by means of figure 1.an example of combining CPCs to make a rule comes as follows:

'If "adequacy of organization" is ineficient, AND "working conditions" are incompatible AND the availability of procedures and plans is inappropriate AND the adequacy of man-machine interface and operational support is acceptable AND the number of simultaneous goals matchs to actual capacity AND the available time is temporary inadequate AND the time of the day is day AND the adequacy of training and experience is adequate with high experience AND the crew collaboration quality is inefficient THEN the operator would act in a OPPORTUNISTIC way.'

Finally, as the fuzzy sets were definded and the rules were constructed in the software Matlab, by assigning the values for each inpute variable, within the specified fuzzy sets, the Software calculates the out-put value which is the probability of human action failure.

Results:

In the case of the control room in Unit 100 of the Methanol production line in a petrochemical industry in Iran the results of Basic, Fuzzy logic and Extended methodology of CREAM are as bellow:
According to the observations and interviews with

technicians and operators in the work environment of control room and using their documentation to have a more reliable assessment, all nine CPCs were evaluated and the level of each CPC, that how they affect the human reliability, is determined. In addition a value is assigned to each CPC by the analyst in order to be used in the fuzzy modeling. The result is shown in table 7. As can be seen from the table 7. Six . CPCs are evaluated as having negative or reduced effect on reliability and six CPCs have no effect on performance of the operator. thus based on the figure 1. The type of control mode is defined as Opportunistic mode. According to the Basic method of CREAM, for this level of control that operator has on their work, an interval probability of 0.01-0.5 is estimated for this case. On the other hand, by putting the CPC values, as are shown in table 7, in the fuzzy logic modeling a crisp value of 0.07 is obtained as the human error probability for the case of study that is within the interval of 0.01 - 0.5.

Table 3. fuzzy sets for input and output variables

Input and output variables			**Membership level intervals**			
Input variables (nine CPCs)	**1**	**Adequacy of organization**	Deficient 0-25	Inefficient 10-60	Efficient 40-90	Very efficient 70-100
	2	**Working condition**	Incompatible 0-30	Compatible 20-80	Advantageous 70-100	
	3	**Adequacy of MMI**	Inappropriate 0-25	Tolerable 10-60	Adequate 40-90	Supportive 70-100
	4	**Availability of procedures**	Inappropriate 0-30	Acceptable 20-80	Appropriate 70-100	
	5	**Number of simultaneous goals**	More than capacity 0-30	Matching current … 20-80	Less than capacity 70-100	
	6	**Available time**	Continuously inadequate 0-30	Temporarily inadequate 20-80	Adequate 70-100	
	7	**Time of day**	Night 6 – 18	Day 0 – 7	Night 17 - 24	
	8	**Adequacy of training**	Inadequate 0-30	Adequate low exp. 20-80	Adequate high experience 70-100	
	9	**Crew collaboration**	Deficient 0-25	Inefficient 10-60	Efficient 40-90	Very efficient 70-100
Output variable (HEP)		**Level of control mode-Human Error Probability(HEP)**	*Scramble* *0.1-1.0*	Opportunistic *0.01-0.5*	Tactical *0.01-0.1*	Strategic *0.00005-0.01*

Table 4. Level of CPCs

CPC	*Level of CPCs*	*Effect on performance reliability*	*Value in fuzzy sets*
Adequacy of organization	*efficient*	*Not significant*	
Working condition	*compatible*	*Not significant*	
Adequacy of MMI	*adequate*	*Not significant*	
Availability of procedures	*acceptable*	*Not significant*	
Number of simultaneous goals	*more than their capacity*	*Negative/reduced*	
Available time	*temporarily inadequate*	*Not significant*	
Time of day	*(night)*	*Negative/reduced*	
Adequacy of training	*inadequate*	*Negative/reduced*	
Crew collaboration	*efficient*	*Not significant*	

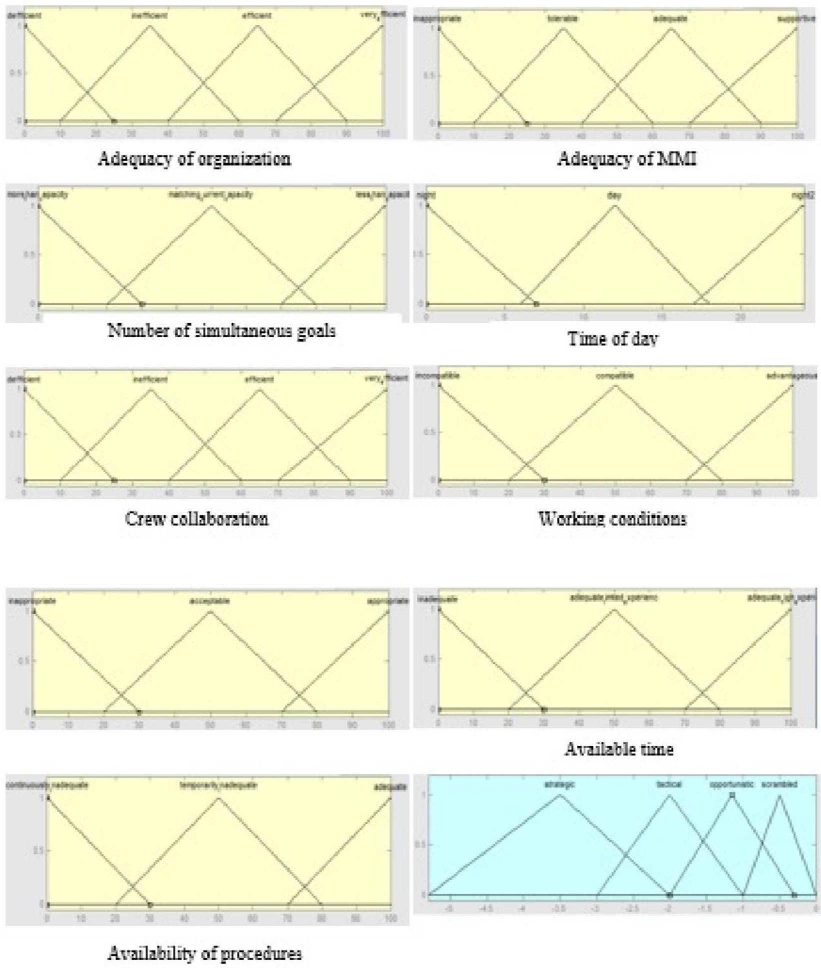

Figure 3. fuzzy sets for input variables(CPCs)

References:

1. Embrey, D., T. Kontogiannis, and M. Green, Guidelines for preventing human error in process safety. Center for Chemical Process Safety, 1994.
2. Peters, G. and B. Peters, Human error: causes and control. 2006: CRC.
3. Wreathall, J., et al., Human reliability analysis in support of risk assessment for positive train control. 2003: US Dept. of Transportation, Federal Railroad Administration, Office of Research and Development, Research and Special Programs Administration.
4. Kirwan, B., Human error identification in human reliability assessment. Part 1: Overview of approaches. Applied Ergonomics, 1992. 23(5): p. 299-318.
5. A. D. Swain and H. E. Guttmann, Handbook of human reliability analysis with emphasis on nuclear power plant applications. NU~G/CR-1278 (1983).
6. JaeW. Kim,1*Wondea Jung,1 and Jaejoo Ha1, AGAPE-ET: A Methodology for Human Error Analysis of Emergency Tasks.
7. Swain AD. Accident sequence evaluation program: human reliability analysis procedure, NUREG/CR-4772, U.S. Nuclear Regulatory Commission, 1987.
8. Hannaman GW, Spurgin AJ, Lukic YD. Human cognitive reliability model for PRA analysis, NUS-4531, Electric Power Research Institute, 1984.
9. Embrey, E., 1984. SLIM-MAUD: An Approach to Assessing Human Error Probabilities Using Structured Expert Judgement NUREG/CR-3518, vols. 1 and 2. USNRC.
10 Williams, J.C., 1992. Toward an improved evaluation tool for users of HEART. In: Proceedings of the International Conference on Hazard Identification, Risk Analysis, Human Factors and Human Reliability Process Safety. Chemical Centre for Process Studies (CCPS),

Orlando.
11. Li Peng-cheng a,b,*, Chen Guo-huaa, Dai Li-cao b, Zhang Li, Fuzzy logic-based approach for identifying the risk importance of human error.
12. Man Cheol Kima, Poong Hyun Seonga, Erik Hollnagel, A probabilistic approach for determining the control mode in CREAM.
13. Swain, A. (1990). Human reliability analysis: Need, status, trends and limitations. Reliability Engineering and System Safety, 29, 301–313.
14. Jung, W. D., Yoon, W. C., & Kim, J. W. (2001). Structured information analysis for human reliability analysis of emer- gency tasks in nuclear power plants. Reliability Engineering and System Safety, 71, 21–32.
15. Hollnagel, E. (1998). Cognitive Reliability and Error Analysis Methodology. London: Elsevier
16. U.S.NRC. (2000). Technical basis and implementation guide- lines for a technique for human event analysis (ATHEANA). NUREG-1624 Rev, 1.
17. Gertman, D., Blackman, H.S., Marble, J., 2005. The SPAR-H Human Reliability Analysis Method, NUREG/CR-6883. US Nuclear Regulatory Commission, Washington, DC.
18. Kim, J.W., Jung, W., Son, Y.S., 2008. The MDTA-based method for assessing diagnosis failures and their risk impacts in nuclear power plant. Reliability Engineering and System Safety 93, 337–349.
19. Sidney W. A. Dekker(2002). The re-invention of human error. Lund University School of Aviation.
20 Hollnagel E. Human reliability analysis—context and control. London: Academic Press; 1993.
21. Onisawa T. Subjective Analysis of system reliability and its analyser. Fuzzy Sets Syst 1996;83:249–69.
22. Konstandinidou, M., Nivolianitou, Z., Kiranoudis, C., Markatos, N., 2006. A fuzzy modeling application of CREAM methodology for human reliability analysis. Reliability Engineering and System Safety 91, 706–716.
23. Kirwan, B. and L. Ainsworth, A guide to task analysis. 1992: CRC.
24. Shepherd, A., Hierarchical task analysis. 2001, Taylor & Francis: London.
25. He, X., et al., A simplified CREAM prospective quantification process and its application. Reliability Engineering & System Safety, 2008. 93(2): p. 298-306.
26. He, X., et al., A simplified CREAM prospective quantification process and its application. Reliability Engineering & System Safety, 2008. 93(2): p. 298-306.

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