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A Fuzzy Reasonal Analysis of Human Reliability Represented as Fault Tree Structure

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ABSTRACT

In conventional probability-based human reliability analysis, the basic human error rates are modified by experts to consider the influences of many factors that affect human reliability. However, these influences are not easily represented quantitatively, because the relation between human reliability and each of these factors is not clear. In this paper, the relation is expressed quantitatively. Furthermore, human reliability is represented by error possibilities proposed by Onisawa, which is a fuzzy set on the interval [0,1].

Fuzzy reasoning is used in this method in order to obtain error possibilities. And, it is supposed that many basic events affected by the above factors are connected to the top event through Fault Tree structure, and an estimate of the top event expressed by a membership function is obtained by using the fuzzy measure and fuzzy integral. Finally, a numerical example of human reliability analysis obtained by this method is given.

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1. INTRODUCTION

The uncertainties and ambiguities involved in many factors that affect human reliability have to be represented as the quantitative forms. In conventional human reliability analysis(HRA), probability-based reliability theory is used to evaluate the effect of these uncertainties but the actual human reliability should be different from that (Pugsley, 1973). In other words, human reliability should not be based on the probability-based reliability theory but on the fuzzy set theory. This is largely due to the expression of actual error causes such as bad quality of procedures, high psychological stress level and unsuitable skill, etc.. Those uncertainties are called "subjective uncertainties", because they are evaluated only by an engineer's experience and judgement(Tsujimura & Gen, 1993). In this paper, the error possibility proposed by Onisawa is used to represent human reliability, and the error possibility is obtained by the use of fuzzy reasoning that plays an important role to clarify the relation between human reliability and human error (Onisawa, 1990). To deal with the above method, several factors that affect human reliability are decided firstly, then the degree of subjective uncertainty of these factors is clarified. Also, assuming these factors are connected to the top event through Fault Tree structure, the influence and correlation of these factors are measured with in the framework of the fuzzy theory. When a fuzzy operation is applied to FTA, it is possible to simplify the operation applying the logic disjunction and logic conjunction to a sturcture function, and the structure of human reliability can be represented as the membership function of the top event. Also, in this paper, an aggregated estimate of the top event is represented as a membership function by a fuzzy measure that is suggested by Sugeno(Sugeno, 1983). Lastly, it is shown that on the basis of membership functions, human reliability can be evaluated using the concept of pattern recognition.

2. EXPRESSION OF HUMAN RELIABILITY USING THE ERROR POSSIBILITY

In HRA, it is a severe restriction for a human evaluator to express the meaning of language as numerical value or to specify the bound of the meaning. In the case that probability-based error rate is used to evaluate human reliability, an approximate error rate may be crisply determined inspite of being fuzziness of the error rate. In this case, there is a major problem that the error rate may lose its precision that is indispenasble for HRA. To solve this problem, an application of fuzzy theory is considered. There are two major approaches in order to apply fuzzy theory to HRA : one approach is based on conventional FTA with fuzzy probabilities defined as fuzzy sets on a probability space(Tanaka, et al., 1983) (Tanaka & Asai, 1981)(Singer, 1990). And another approach is based on fuzzy measures with error possibilities that are equivallent to fuzzy probabilities (Onisawa, 1988a) (Onisawa, 1993) (Nishiwaki, 1985). Thus, the difference between them stems from different measures.

Let us define an error possibility or a fuzzy probability as a fuzzy set on a probability space [0,1]. A typical example is as follows(Onisawa & Nishwaki, 1988) (Onisawa, 1988b) :

$$E(x) = \frac{1}{1 + 20 \times |x - x_o|^m} \qquad (1)$$

where $m = m_L$ for $x \leqq x_o$ and $m = m_U$ for $x > x_o$.

The parameter m is related to fuzziness, and x_o gives the maximal grade of $E(x)$, i.e., $E(x_o) = 1$. E is called error possibility and x is called likelihood of error. The parameter x_o and m are assumed to be derived from the triplet of the basic error rates $[P_L, P_M, P_U]$, where P_M is the recommended value of the error rate, P_L is its lower bound, and P_U is its upper bound.

(1) implies that even if x_o is very small, there exists a possibility that a human evaluator may make an error since $E(x) > 0$ for all $x \in [0,1]$. Here, x_o is assumed to derive the error possibility from the estimates of fuzzy reasoning. At present it is better to connect error possibilities with error rates since we have only a few data with respect to human errors. For example, if x_o is small and m is large, then its distribution shows the high error possibility that a human error will happen to this case. On the other hand, if x_o is large and m is small, then its distribution shows the low error possibility that a human error will happen.

3. LINGUISTIC EXPRESSION OF HUMAN RELIABILITY

Fuzzy sets theory has been proposed as a useful means of dealing with uncertainties. After that, the possibility theory has been developed as a branch of fuzzy sets theory. The concept of error possibility has been proposed to represent human reliabiltiy instead of error rate which is used in conventional probability-based HRA. It is very difficult to express the relation between human reliability and the possibility of error, but the relation can be clarified clearly by the use of fuzzy reasoning. To obtain error possibility distributions, in this paper, the relations of the typical three factors which affect human reliability are expressed quantitatively and the value of x_o is obtained through the fuzzy reasoning.

We consider the three factors such as quality of procedures, psychological stress level and skill. Furthermore, as described in the above, representing the qualitative relation between human reliability and these factors is not easy but expressing the relation of them as a form of linguistic variables is possible as belows,

* quality of procedures
  If the quality of procedures is good, then human reliability is high.
  If the quality of procedures is bad, then human reliability is low.
* psychological stress level
  If the psychological stress level is low, then human reliability is somewhat low.
  If the psychological stress level is optimal, then human reliability is high.
  If the psychological stress level is high, then human reliability is low.
* skill
  If the degree of skill is high, then human reliability is high.
  If the degree of skill is low, then human reliability is low.

Terms "good", "bad", "high", "low", "somewhat low", and "optimal" are expressed by a fuzzy subset of the unit interval [0,1].

Figure 1. illustrates the above quantitative expressions by use of fuzzy sets. Fuzzy sets to the left of the arrows show the terms "good", "bad", and so on, to estimate the factors that affect reliability. The

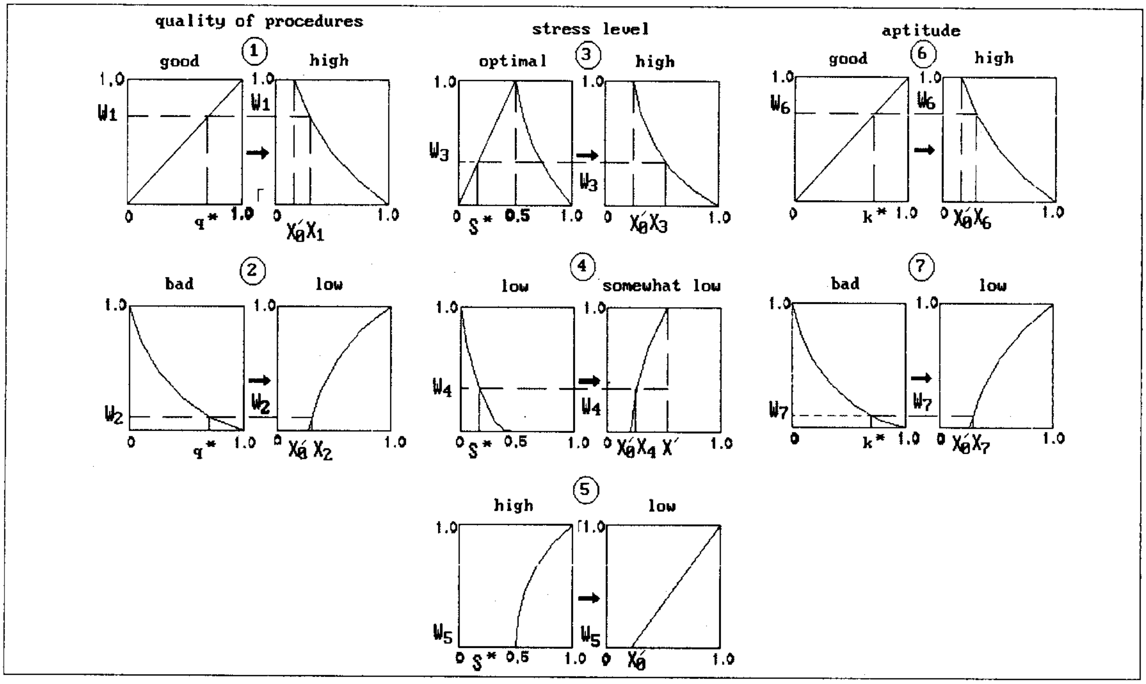

Figure 1. Human Reliability with Fuzzy Reasoning

numerical value of the ordinate shows the estimate of each factor. On the other hand, fuzzy sets to the right of the arrow show the terms "low", "high", and so on, on reliability in terms of x_o in Equation 1. In the case of the low psychological stress level, because a decline of reliability is little, the parameter x' that represents the fuzzy set of "somewhat low" is expressed as (2)(Onisawa, 1988).

$$x' = \frac{x'_o + 1}{2} \tag{2}$$

Where x'_o is obtained from the triplet $[P_L, P_M, P_U]$ of the basic error rates as followed.

$$x'_o = \frac{1}{1 + \{\log(1/P_M)/\log(1/P_U)\}^3} \tag{3}$$

4. CALCULATION OF x_o BY FUZZY REASONING

Let $h_{qi}(x)(i=1, 2)$, $h_{si}(i=3, 4, 5)$, $h_{ki}(i=6, 7)$ and $g_i(i=1, 2, \cdots, 7)$ be the membership functions of fuzzy sets representing the quality of procedures, psychological stress level, skill and human reliability, respectively, then the parameter x_o in Equation 1 is obtained by use of fuzzy reasoning when the estimates of the factors $x_i(i=1, 2, \cdots, 7)$ are given. The procedure of fuzzy reasoning can be described as follows :

1. Calculate

$$\text{i)} \begin{cases} y_i = h_{qi}(q^*) & (i=1,2) \\ y_i = h_{si}(s^*) & (i=3,4,5) \\ y_i = h_{ki}(k^*) & (i=6,7) \end{cases} \tag{4}$$

where y_i implies the degree of satisfaction in the IF part (antecedent).

2. Find x_i such that

$$\text{ii)}\ y_i = g_i(x_i) \quad (i=1,\ldots,7). \tag{5}$$

3. Calculate

$$\text{iii)}\ x_o = \frac{\sum_{i=1}^{7} x_i \cdot y_i}{\sum_{i=1}^{7} y_i}. \tag{6}$$

When the estimate of each factor on human reliability is the best, that is, for $q^*=1$, $s^*=0.5$, $k^*=1$, the inferred is $x_o = x'_o$. This implies that even if a human operator performs a certain task under the best conditions, there is a possibility that he will fail in the task. On the other hand, in the case that the condition of tasks is the worst one, that is $q^*=0$, $s^*=1$ (or $s*=0$) and the inferred is $x_o=1$.

Through the above procedures, the value of m of Equation 1 is obtained as follows :

1. From the value of x_o obtained by (4), (5) and (6), human reliability is classified as Table 1.

Table 1. Classification of Human Reliability

class	expression of reliability	x_o(typical value)
	(human reliability is)	
C_1	none	-
C_2	very low	0.9 -1.0 (0.95)
C_3	low	0.7 -0.9 (0.8)
C_4	somewhat low	0.5 -0.7 (0.6)
C_5	standard	0.3 -0.5 (0.4)
C_6	high	0.2 -0.3 (0.25)
C_7	somewhat high	0.1 -0.2 (0.15)
C_8	very high	0.05-0.1 (0.075)
C_9	human error is near zero	0.0 -0.05(0.025)
C_{10}	human error is zero	-

2. The parameter m is obtained from the triplet of the basic error rates [P_L, P_M, P_U].

3. Using (3), we obtain $P*$.

$$x*_o = f(P*) = \frac{1}{1 + \{ K \times \log(1/P*) \}^3}$$

4. From $N = P*/P_M$, determine the range of k of Table 2.

5. From Table 3., determine m_L, m_U.

Table 2. Range of k

class	m_L			
	$N \leqq 3$	$3 < N \leqq 5$	$5 < N \leqq 10$	$10 < N$
C_2	m_L in $3 < k \leqq 5$		m_L in $k \leqq 3$	
C_3	m_L in $3 < k \leqq 5$		m_L in $k \leqq 3$	
C_4	m_L in $k \leqq 3$			
C_5	m_L in $k \leqq 3$			
C_6	m_L in $5 < k \leqq 10$			m_L in $k \leqq 3$
C_7	m_L in $5 < k \leqq 10$			m_L in $k \leqq 3$
C_8	m_L in $5 < k \leqq 10$			m_L in $k \leqq 3$
C_9	m_L in $5 < k \leqq 10$			m_L in $k \leqq 3$
class	m_U			
	$N \leqq 3$	$3 < N \leqq 5$	$5 < N \leqq 10$	$10 < N$
C_2	m_U in $3 < k \leqq 5$		m_U in $5 < k \leqq 10$	m_U in $10 < k$
C_3	m_U in $3 < k \leqq 5$		m_U in $5 < k \leqq 10$	m_U in $10 < k$
C_4	m_U in $k \leqq 3$	m_U in $3 < k \leqq 5$	m_U in $5 < k \leqq 10$	m_U in $10 < k$
C_5	m_U in $k \leqq 3$	m_U in $3 < k \leqq 5$	m_U in $5 < k \leqq 10$	m_U in $10 < k$
C_6	m_U in $5 < k \leqq 10$			m_U in $10 < k$
C_7	m_U in $5 < k \leqq 10$			m_U in $10 < k$
C_8	m_U in $5 < k \leqq 10$			m_U in $10 < k$
C_9	m_U in $5 < k \leqq 10$			m_U in $10 < k$

Table 3. Value of m_L, m_U

class	m_L, m_U			
	$k \leqq 3$	$3<k \leqq 5$	$5<k \leqq 10$	$10<k$
C_2	2.7, 2.7	3.3, 3.3	4.0, 4.0	4.7, 4.7
C_3	1.3, 3.1	1.7, 3.8	2.0, 4.6	2.3, 5.4
C_4	1.9, 2.6	2.4, 3.3	2.9, 3.9	3.4, 4.6
C_5	2.0, 2.0	2.5, 2.5	3.0, 3.0	3.5, 3.5
C_6	1.6, 1.5	1.9, 1.9	2.3, 2.3	2.7, 2.7
C_7	1.1, 1.2	1.4, 1.5	1.7, 1.8	1.9, 2.1
C_8	0.8, 0.9	1.0, 1.1	1.1, 1.4	1.3, 1.6
C_9	0.5, 0.7	0.6, 0.8	0.7, 1.0	0.9, 1.2

5. STRUCTURAL MODEL OF HUMAN RELIABILITY ON FAULT TREE

5.1 Representation of structure function

In FTA, a structure function $\psi(\underline{x})$ is used to define the state of the top event and to evaluate the influence of each basic event on the top event. Now if we let x_i be the state of the i-th basic event, then structure functions of AND and OR gates are defined as follows,

$$\psi_{AND}(\underline{x}) = \prod_{i=1}^{m} x_i \tag{8}$$

$$\psi_{OR}(\underline{x}) = \coprod_{i}^{m} x_i \triangleq 1 - \prod_{i=1}^{m} (1 - x_i) \tag{9}$$

where $\underline{x}$ means the vector that consists of $(x_1, x_2, \cdots, x_m)$ and m is the number of basic events. A Fault Tree, in general, involves many AND and OR gates which are complicatedly combined. For this reason, it is a time-consuming work to estimate the state of the top event directly from (8) and (9). If a Fault Tree has so many basic events, to reduce the computation load, we utilize the definition of Min and Max operations instead of Equation (8) and (9).

$$\psi_{AND}(\underline{x}) = \bigwedge_{i=1}^{m} x_i \triangleq Min\ x_i \tag{10}$$

$$\psi_{OR}(\underline{x}) = \bigvee_{i=1}^{m} x_i \triangleq Max\ x_i \tag{11}$$

The above definitions completely correspond to the fundamental properties of fuzzy calculations that all arithmetic enumerations are performed only by Min and Max operations. Comparing Equation (8) and (9) with (10) and (11) have the advantage that the structure function can be directly computed without any special treatments.

5.2 The weights of basic events

Let $A_1, A_2, \cdots, A_n$ be n objects in pairs according to their relative weights. We are interested in evaluating ranking among $A_1, \cdots, A_n$. Saaty proposed the use of matrix $\boldsymbol{A}$ of rational numbers taken from the finite set {1/9, 1/8, ⋯1, 2, ⋯8, 9}. Each entry of the above matrix $\boldsymbol{A}$ represents a pairwise comparison. Specifically, the entry a_{ij} denotes the relative goodness of element A_i, compared with element A_j. Obviously, $a_{ij} = 1/a_{ji}$ and $a_{ii} = 1$. That is, the matrix $\boldsymbol{A}$ is a reciprocal one. The pairwise comparisons are quantified by using the scale decribed in Saaty's paper(Satty, 1977).

Note that if object i has one of the above non-zero values when compared with object j, then j has the reciprocal value when compared with i. Let us first consider the ideal case(the consistent case) in which a_{ij} is assigned to w_i/w_j where w_i is a true weight of element A_i. Thus the pairwise comparisons can be represented by

$$A = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ \vdots & \vdots & & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix}$$

Multiplying $\boldsymbol{A}$ by the vector $\boldsymbol{w} = (w_1, \cdots, w_n)^t$, we can obtain

$$\boldsymbol{Aw} = n\boldsymbol{w},$$

thus, n is an eigenvalue of $\boldsymbol{A}$ and $\boldsymbol{w}$ is an eigenvector.

In the non-consistent case which is more common in practice, the pairwise comparisons are not perfect, that is, the entry a_{ij} might be deviate from the real ratio w_i/w_j. Now the matrix $\boldsymbol{A}$ can be considered as a perturbation of the previous consistent case. As the entries a_{ij} change slightly, the eigenvalues change in a similar fashion. Moreover, the maximum eigenvalue is close to n or greater than n while the remaining eigenvalues are close to zero. In this paper, w_i is transformed to a membership value of a unit interval [0,1] in order to apply fuzzy opetation of error possibilities and the weights.

By letting $\mu_{G_i}(x)$ be the confidence of occurrence and $\mu_{w_i}(x)$ be the membership value of the weight w_i(its maximum value is 1.0), the membership function of each basic event $\mu_{E_i}(x)$ can be calculated as

$$\mu_{E_i}(x) = \mu_{G_i}(x) \vee \mu_{w_i}(x),\ x \in [0,1]. \qquad (12)$$

Also, the membership function of the top event $\mu_{E_T}(x)$ is obtained as

$$\mu_{E_T}(x) = \phi(\underline{\mu}_{E_i}), \qquad (13)$$

where $\underline{\mu}_{E_i}$ is a vector that consists of components $\mu_{E_i}(x)$.

6. SIMILARITY ASSESMENT OF HUMAN RELIABILITY

Although many methods have been suggested to solve the problem of linguistic expression of human reliability that is represented as fuzzy sets, there is no satisfying general solution to solve this problem because of its difficulties. When the estimates of human reliability of each basic event is connected to the aggregated estimate on the top event through Fault Tree with structure functions, the similarity of human reliability pattern can be evaluated by comparing membership function of the aggregated estimate with that of the predetermined typical reliability patterns.

In this paper the similarity of human

reliability pattern is evaluated on the basis of the distance of two fuzzy sets.

Let F_R be the error possibility which is obtained by HRA and let F_S be the error possibility of typical pattrens with its membership function that is obtained by use of Equation 1.

Let the α-level set of F_R and F_S be $(F_R)\alpha = (x_{1R}(\alpha),\ x_{2R}(\alpha))$, and $(F_s)_\alpha = (x_{1s}(\alpha),\ x_{2s}(\alpha))$, respectively. Then the distance between F_R and F_S can be defined as follows.

$$d = \int_0^1 [\ x_{1R}(\alpha) - x_{1S}(\alpha)^2 + x_{2R}(\alpha) - x_{2S}(\alpha)^2]^{1/2} d\alpha \qquad (14)$$

To simplify (14), let the membership function of aggregated human reliability be $\mu_{iE_T}(x)$ and the membership function of the typical patterns k $(k = 1, 2, \ldots, l)$ depicted in Figure 2. be $\mu_{jE_T}(x)$. Then the distance of $\mu_{iE_T}(x)$ and $\mu_{jE_T}(x)$ can be defined as

$$V_k = \int_0^1 \mid \mu_{i_{ET}}(x) - \mu_{j_{ET}}(x) \mid dx \qquad (15)$$

where $k(k = 1, 2, \ldots, l)$ is the number of typical patterns such as "very low(a)", "low(b)", "somewhat low(c)", "standard(d)", "high(e)", "somewhat high(f)" and "very high(g)". These seven patterns are dipicted in Figure 2.

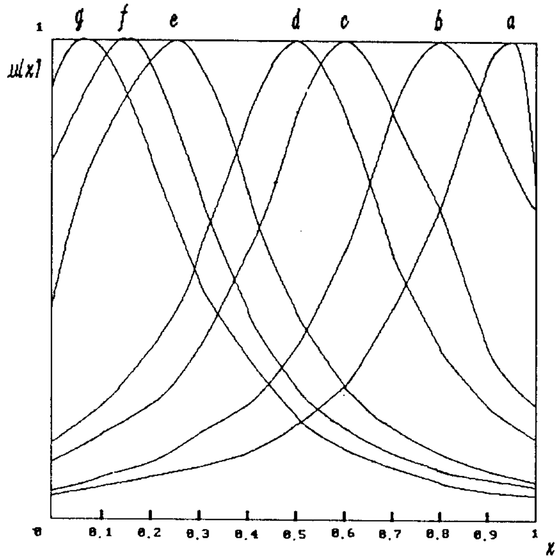

Figure 2. Examples of Typical Patterns

7. EVALUATION OF HUMAN RELIABILITY USING FUZZY MEASURE AND FUZZY INTEGRAL

In obtaining the weights of each basic events by pairwise comparisons and evaluating an aggregated estimate using these weights, there is a major problem in the use of the additive and linear model. To solve this problem, fuzzy measures are used. While the conventional Lebesgue measure assumes additivity, fuzzy measure assumes only monotonicity and thus is very general(Murofushi & Sugeno, 1991). Hence, human subjective scales can be better approximated using fuzzy measures than using the additive ones.

Sugeno constructed the λ-measure as a special case of fuzzy measures. Where λ is a parameter of fuzzy measure. Sugeno presented the fuzzy measure and fuzzy integral as a means to express human subjective evaluation process. This paper presents a mathematical model for the human subjective evaluation process using fuzzy integral based on the λ-fuzzy measure. While fuzzy measures are scales of human subjective evaluation, fuzzy integrals can be interpreted as operations that quantify human evaluation based on these measures.

The fuzzy measure and integral have been proposed for interpreting the membership function $\mu_{E_T}(x)$ in a more clear and quantitative manner as subjective measure of ambiguous objects. Fuzzy measure g_λ is defined from the fuzzy distribution function as

$$H(x):$$
$$H(x_k) = g_{\lambda_k} + H(x_{k-1}) + \lambda g_{\lambda_k} H(x_{k-1}),$$
$$H(x_1) = g_{\lambda_1}, \qquad (16)$$

where $H(x)$ is discretized and $0 \le H(x_1) \le H(x_2) \le \cdots \le H(x_k) = 1$. If λ is zero, g_λ becomes a probability measure which satisfies the requirement of additivity.

For a function $h(x)$, the fuzzy integral is defined as follows:

$$\int h(x_k) \circ g_\lambda = \bigvee_{k=1}^{n} [h(x_k) \wedge H(x_k)]. \quad (17)$$

Replacing the $h(x_k)$ and g_λ by x_k and $\mu_{E_T}(x)$, a representative value $x*$ of human reliability, can be obtained as follows:

$$x* = \bigvee_{k=1}^{n} [x_k \wedge H\mu_{E_T}(x_k)]. \qquad (18)$$

8. NUMERICAL EXAMPLE

The quality of procedures, psychological stress level and skill of a human operator are supposed as the factors that affect human reliability of basic events. Furthermore, it is assumed that human reliability of the top event is aggregated with that of nine basic events ①, ②, ⋯, ⑨ and seven intermediate events G1, ⋯, G7 through AND and OR gates as Figure 3.

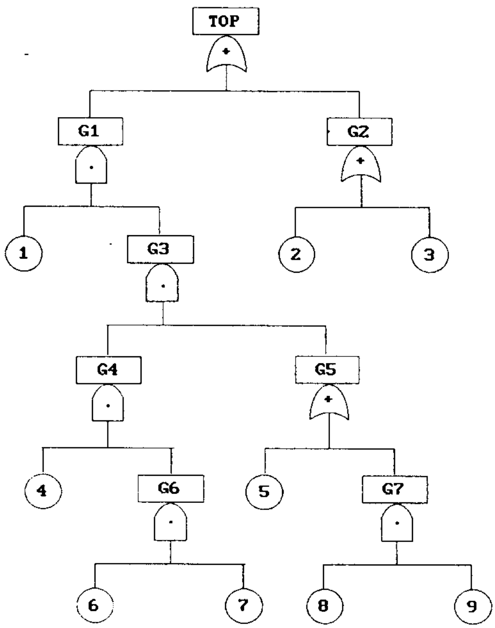

Figure 3. Example of Fault Tree

Table 4. Subjective Estimates of Basic Events

basic event	①	②	③	④	⑤	⑥	⑦	⑧	⑨
quality of procedures($q*$)	1.0	0.5	0.3	0.6	0.7	0.8	0.9	0.4	0.8
stress level($s*$)	0.5	0.3	0.5	0.7	0.4	0.6	0.3	0.8	0.2
skill($k*$)	1.0	0.5	0.8	1.0	0.8	0.7	0.5	0.4	0.6

In this example, the subjective estimates of three factors are illustrated in Table 4.

Furthermore, in order to obtain the estimate of human reliability of each basic event, consider the relative weights of basic events given as a reciprocal matrix.

When the eigenvector approach is applied to the reciprocal matrix, the vector of numerical value w'_i can be calculated. When the eigenvector is transformed such that its maximum value is 1.0, the resulting vector w is

$$w = (0.66, 0.22, 0.49, 1.0, 0.16, 0.3, 0.36, 0.86, 0.42).$$

The human reliability of the basic,

Table 5. Estimates of Paired-comparison

	①	②	③	④	⑤	⑥	⑦	⑧	⑨
①	1	3.5	1.5	0.67	4	2.5	2	0.67	1.5
②	0.29	1	0.4	0.2	1.2	1.33	0.67	0.25	0.5
③	0.67	2.5	1	0.56	3.5	2	1.5	0.67	0.67
④	1.5	5	1.8	1	6	4	3	1.2	2.5
⑤	0.25	0.83	0.29	0.17	1	0.67	0.5	0.18	0.4
⑥	0.4	0.75	0.5	1.5	1.5	1	0.67	0.33	0.67
⑦	0.5	1.5	0.67	0.33	2	1.5	1	0.4	1.33
⑧	1.5	4	1.5	1	5.5	3	2.5	1	2
⑨	0.67	2	1.5	0.4	2.5	1.5	0.75	0.5	1

Table 6. The Resulting Membership Function $\mu_{E_T}(x)$ of the Top Event

x	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
$\mu_{E_T}(x)$	0.49	0.49	0.49	0.49	0.49	0.62	0.91	1.0	1.0	0.97	0.86

intermediate and top event may be acquired through Min or Max operation as Equation (10), (11) and (12), (13) with considering the connection of these events with AND gates or OR gates. The resulting membership function $\mu_{E_T}(x)$ of the top event is obtained as below.

The similarity between the typical and aggregated human reliability can be calculated by V_k of (15). Those are as follows:

$$V(a)=4.11,\quad V(b)=2.98\ ,\quad V(c)=3.28,$$
$$V(d)=4.07,\quad V(e)=5.47,\quad V(f)=5.85,$$
$$V(g)=6.02.$$

In this case, the human reliability of the top event can be expressed as 「low」. In order to obtain the representative value of aggregated human reliability of the top event, let x_k, the function to be integrated, is arranged in ascending order and $\mu_{E_T}(x_k)$ is normalized into $\mu'_{E_T}(x_k)$ such that its sum is 1.0. In this case, the value of λ that satisfies the condition $-1<\lambda<\infty$ is given as $\lambda=-0.00221367$. That is :

$$1 = \{\mu_{E_T}(0)+\mu_{E_T}(0.1)+\cdots+\mu_{E_T}(1.0)\}+\cdots+[\{\mu_{E_T}(0)\times\mu_{E_T}(0.1)\}+\{\mu_{E_T}(0)\times\mu_{E_T}(0.2)\}+\cdots+\{\mu_{E_T}(0.9)\times\mu_{E_T}(1.0)\}]\lambda+[\{\mu_{E_T}(0)\times\mu_{E_T}(0.1)\times\mu_{E_T}(0.2)\}+\cdots+\{\mu_{E_T}(0.8)\times\mu_{E_T}(0.9)\times\mu_{E_T}(1.0)\}]\lambda^2+[\{\mu_{E_T}(0)\times\mu_{E_T}(0.1)\times\mu_{E_T}(0.2)\times\mu_{E_T}(0.3)\}+\cdots+\mu_{E_T}(0.7)\times\mu_{E_T}(0.8)\times\mu_{E_T}(0.9)\times\mu_{E_T}(1.0)\}]\lambda^3+\cdots+[\{\mu_{E_T}(0)\times\mu_{E_T}(0.1)\times\cdots\times\mu_{E_T}(0.9)\}+\{\mu_{E_T}(0.1)\times\mu_{E_T}(0.2)\times\cdots\times\mu_{E_T}(1.0)\}]\lambda^9+\{\mu_{E_T}(0)\times\mu_{E_T}(0.1)\times\cdots\times\mu_{E_T}(1.0)\}\lambda^{10}. \quad (19)$$

Approximating $\lambda\cong 0$, a representative value is obtained as 0.4* by use of (16), (17) and (18), that is : the representative value of human reliability can be interpreted as 0.4.

8. CONCLUSION

In this paper, after finding the relation

Table 7. The Results of Fuzzy Integral

x	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
x_k	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0
$\mu_{E_T}(x)$	0.49	0.49	0.49	0.49	0.49	0.62	0.91	1.0	1.0	0.97	0.86
$\mu'_{E_T}(x_k)$	0.063	0.063	0.063	0.063	0.063	0.079	0.117	0.128	0.128	0.124	0.110
$H\mu'_{gE_T}(x_k)$	0.063	0.126	0.189	0.252	0.315	0.394	0.511	0.639	0.767	0.891	1.0
$x_k \wedge H$	0.063	0.126	0.189	0.252	0.315	0.394	0.4*	0.3	0.2	0.1	0

between human errors occurred in subjective uncertainty and their causes which are quantified, a rational method of HRA that is capable of interpreting more clearly the structure of human reliability is proposed.

And the error possibility which is a fuzzy set on the interval [0,1] is used to represent human reliability as a membership function. By use of fuzzy reasoning, a method is proposed to derive error possibility from the subjective estimation of not only the basic human error rates but also many factors that affect human reliability.

When it is supposed that many basic and intermediate events are hierarchically connected to the top event through the Fault Tree structure, by applying fuzzy operation to FTA, it is possible to simplify the operation by use of logic disjunction and logic conjunction to a structure function and the structure of human reliability can be represented as a membership function

In order to evaluate the influence of human error, the fuzzy measure and fuzzy integral proposed by Sugeno are used. And it is shown that the human reliability of the top event can be expressed by linguistic variables using the concept of pattern recognition.

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